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AGARD Flight Test Techniques Series Volume 8 on Flight Testing Under Extreme Environmental Conditions

by

C.L. Hendrickson

Edited by

R.K. Bogue

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AGARDograph No.300 Vol.8

FLIGHT TESTINC UNDER EXTREME ENVIRONMENTAL CONDITIONS

by

C.L.Hendrickson

A Volume of the

AGARD FLIGHT TEST TECHNIQUES SERIES

Edited by

R.K.Bogue

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PREFACE

Since its founding in 1952, the Advisory Group for Aerospace Research and Development has published, through the Flight Mechanics Panel, a number of standard texts in the field of flight testing. The original Flight Test Manual was published in the years 1954 to 1956. The Manual was divided into four volumes: I. Performance, II. Stability and Control, III. Instrumentation Catalog, and IV. Instrumentation Systems.

As a result of developments in the field of flight test instrumentation, the Flight Test Instrumentation Group of the Flight Mechanics Panel was established in 1968 to update Volumes III and IV of the Flight Test Manual by the publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, the Flight Mechanics Panel decided that further specialist monographs should be published covering aspects of Volume I and II of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group was established to carry out this task. The monographs of this Series (with the exception of AG 237 which was separately numbered) are being published as individually numbered volumes of AGARDograph 300. At the end of each volume of AGARDograph 300 two general Annexes are printed; Annex 1 provides a list of the volumes published in the Flight Test Instrumentation Series and in the Flight Test Techniques Series. Annex 2 contains a list of handbooks that are available on a variety of flight test subjects, not necessarily related to the contents of the volume concerned.

Special thanks and appreciation are extended to Mr F.N.Stoliker (US), who chaired the Group for two years from its inception in 1981 and established the ground rules for the operation of the Group.

The Group wishes to acknowledge the many contributions of E.J.(Ted) Bull (UK), who passed away in January 1987.

In the preparation of the present volume the members of the Flight Test Techniques Group listed below have taken an active part. AGARD has been most fortunate in finding these competent people willing to contribute their knowledge and time in the preparation of this volume.

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ABSTRACT

The major objective of Flight Testing under extreme environmental conditions is to determine to what extent a weapon system, including its essential support equipment and attendant crews can accomplish the design mission in the required climatic extremes, using Technical Order procedures. Such testing has historically often revealed design deficiencies that impact the operational capabilities of the air vehicle involved.

This volume in the AGARD Flight Test Techniques Series discusses the philosophy, purpose and methods for conducting ground and flight tests of weapon systems in extreme environmental conditions. The areas considered include testing in a controlled artificial environment, as well as cold arctic, desert, tropic, and adverse-weather conditions. Also included are the technical and safety aspects of planning, instrumentation and data acquisition requirements, types of tests conducted and reporting requirements.

* * *

Le but principal des essais en vol effectués dans des conditions d'environnement limites est de déterminer dans quelle mesure un système d'armes, les équipements de support associés ainsi que les équipages peuvent accomplir leur mission telle que définie dans les documents d'étude dans des conditions climatiques extrêmes et imposées, ceci en suivant strictement les instructions données dans les manuels techniques appropriés.

Dans le passé de tels essais ont souvent mis en évidence des imperfections de conception ayant des incidences sur les capacités opérationnelles du véhicule aérien en question.

Le présent volume AGARD discute la philosophie des techniques d'essai en vol et propose des méthodes pour conduire des essais au sol et en vol pour des systèmes d'armes dans des conditions d'environnement extrêmes. Les domaines étudiés comprennent les essais en environnement artificiel contrôlé, ainsi que dans des conditions tropicales, de froid polaire, d'ambiance saharienne et dans des conditions météorologiques hostiles. D'autres sujets tels que les aspects techniques et de sécurité de la planification, les spécifications en matière d'instrumentation et la saisie de données, les différents types d'essais effectués et l'élaboration de comptes-rendus de spécifications y sont également traités.

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LIST OF ABBREVIATIONS

Customary (U.S) units were used throughout this report, backed up by System International units (SI) where applicable. Units of measurement were spelled out in the body of the report, and abbreviations were used on tables and figures.

A&AEE	Aeroplane and Armament Experimental Establishment
A/A	air-to-air
ac	alternating current
ADG	aircraft driven gearbox
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AFFTCR	Air Force Flight Test Center Regulation
AFR	Air Force Regulation
AFSC	Air Force Systems Command
AFSCR	Air Force Systems Command Regulation
AGARD	Advisory Group for Aerospace Research and Development
Ammo	ammunition
amps	amperes
auto	automatic
ck	check
comm/nav	communication/navigation
compt	compartment
degrees C	degrees Celsius
degrees F	degrees Fahrenheit
ECS	environmental control system
EM	electromagnetic
EPU	emergency power unit
exp	explosion
Ext/Ret	extend and retract
FCS	flight control system
GSE	ground support equipment
HFT&E	Human Factors Test and Evaluation
H_g	mercury
H_2O	water
Hq	headquarters
Hr	hour
HUD	head-up display

Hx	heat exchanger
Hyd	hydraulic
Hz	Hertz (cycles per second)
IDG	integrated drive generator
IFF	indentification friend or foe
IFR	instrumentation flight rules
ILS	instrumentation landing system
INS	inertial navigation system
Insp	inspection
Intercomm	intercommunication
JFS	jet fuel starter
MCAS	Marine Corps Air Station
MIL-STD	Military Standard
N_1	low pressure compressor RPM
N_2	high pressure compressor RPM
NAF	Naval Air Facility
N_x	longitudinal acceleration
N_y	lateral acceleration
N_z	vertical acceleration
REO	radar electrical optical
RPM, rpm	revolutions per minute
R&R	remove and replace
SI	System International (Units)
TACAN	tactical air navigation
TIH	Technical Information Handbook
UHF	ultrahigh frequency
UK	United Kingdom
U.S.	United States
USAF	United States Air Force
Vac	volts alternating current
Vdc	volts direct current

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FLIGHT TESTING UNDER EXTREME ENVIRONMENTAL CONDITIONS

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SUMMARY

This document discusses the philosophy, purpose and methods for conducting ground and flight tests of weapon systems in extreme environmental conditions. The areas considered include testing in a controlled environment, cold arctic, hot desert, tropic, and adverse weather conditions. Also included are the technical and safety aspects of planning, instrumentation and data acquisition requirements, types of tests conducted and reporting requirements.

1. INTRODUCTION

Flight testing under extreme environmental conditions historically has revealed design deficiencies that impact the operational capabilities of the air vehicle involved. This testing ensures evaluation of air vehicle weapon systems effectiveness under varying or extreme natural environmental conditions and enables predetermination of an acceptable risk level. The major objective of all-weather testing is to determine to what extent a weapon system, including its essential support equipment and attendant crews can accomplish the design mission in the required climatic extremes, using technical order procedures.

1.1 Background

The author, having spent 12 years actively engaged in or managing all-weather tests, was commissioned by the Advisory Group for Aerospace Research and Development (AGARD) Flight Mechanics Panel to develop this AGARDograph. Fact-finding trips were made to a number of locations where personnel operate equipment in extreme climatic conditions or where people reside who had experience in operating or testing in extreme climatic conditions. A list of these locations is contained in Table 8 of the Appendix, Section 8.4. The material contained in this document is purposely generic in nature and does not discuss weaknesses or strengths of any particular organization or weapon system. The information obtained during these fact-finding trips is spread throughout the document. <u>If a statement or bit of material can be identified as having come from a particular organization or individual, that information is followed by a number, e.g., (12), which corresponds to the visit number contained in Table 8.</u>

Environmental testing of United States military equipment dates back to 1934 when a military review recommended that tactical units be trained in various parts of the United States under winter conditions, and that at least one composite squadron undergo all year training in Alaska on a continuing basis. This recommendation led to the establishment of Ladd Field at Fairbanks, Alaska, and in 1942 cold weather testing began on a regular basis.

A cold weather test detachment operating under the Alaskan Defense Command faced many difficult problems. Many manufacturers and government agencies doubted the necessity and desirability of cold weather test operations. Transportation was difficult and sometimes hazardous. Lack of trained and experienced personnel hampered operations. Weather, because of its uncertainty, played havoc with test schedules.

In 1943, the cold weather testing mission was assigned to the Army Air Proving Ground Command, which subsequently evolved into the Air Force Systems Command Armament Division. Two men, Colonel H. O. Russell and Lieutenant Colonel A. C. McKinley, were instrumental in developing climatic test policies and facilities in the United States.

Lieutenant Colonel McKinley, because of his experience in ferrying aircraft to the Soviet Union, suggested that all aircraft and equipment be operable at temperatures as low as -65 degrees F (-54 degrees C), and that a refrigerated hangar be constructed at Eglin Air Force Base (AFB), Florida, to produce such an environment under controlled conditions. The reasons for such a testing facility were numerous. By 1944, the United States had become a global power with forces deployed worldwide, and the future demanded a force capable of operations in all global environments. Further, since testing in Alaska was expensive and had produced only meager results, Lieutenant Colonel McKinley reasoned that testing under controlled conditions would be far superior in useful results and up to 10 times more economical. This estimate later proved to be close to the actual savings realized. In later years, the role of the Climatic Laboratory became that of a valuable foundation for testing in natural extreme climatic environments. The initial cost was estimated at nearly $2,000,000. The actual cost, at the end of construction, had risen to $5,500,000, indicative of the many problems encountered by designers and builders.

Testing in the Climatic Laboratory began in May 1947. The first items tested included the Fairchild C-82, Boeing B-29, Lockheed P-80, North American P-51, Lockheed P-38, and the Sikorsky R-5D helicopter. Temperatures of -70 degrees F (-57 degrees C) were reached. By 1970 over 200 aircraft, 55 missiles and missile support systems, and over 1400 miscellaneous items of equipment had been tested in the Climatic Laboratory.

Indicative of progress, due to testing in extreme environmental conditions, is the advancement of turbojet engine performance. Early designs of these engines were plagued by inadequate starting and fuel control systems, and compressor stalls at extreme environmental conditions. The Climatic Laboratory has been a major factor in diagnosing these problems and improving engine reliability.

1.2 Basic Philosophy

Out of the years of testing has grown a philosophy equally applicable to all services and agencies. This philosophy embraces the concepts that extreme environmental testing of weapon systems is a vital necessity in any global military effort, and that a most important benefit is the improvement in overall systems reliability. As operational theaters continue to expand and systems become more complex, reliability and operational capability must be maintained. Through environmental testing, we can study and understand the mechanics of failure and thus improve weapon system reliability and maintainability.

Flight testing under extreme environmental conditions ensures weapon systems can be operationally effective under varying, or extreme natural conditions, with a predetermined acceptable risk. Some weapon systems and support equipment must be capable of worldwide deployment and operation on short notice. This commitment requires that such systems be capable of withstanding all of the extremes of worldwide climates while carrying out assigned missions with a minimum loss of effectiveness due to climate-related limitations. It is not possible to determine what climates a vehicle will operate in and test only for those extremes. To do so would require accurate predictions of the time and place of all future military action. Most military aircraft have been exposed to nearly all climatic extremes at one time or other.

A comment from the Canadian Methods Book on Climatic Test Work (Ref 1): "Always to be borne in mind should be the requirement to operate, not just one aircraft but a number of aircraft, perhaps in squadron or wing strength, or perhaps one aircraft at a time taken at random from a fleet. Hence, individual improvisation is no longer good enough. Moreover, one must take strong issue with the philosophy that this aircraft 'will always operate from a heated shelter'. What will happen if a given military situation demands the moving of a squadron to a field without shelters? Or what if the energy needed to heat available shelters is not available? What if the shelters have been destroyed?"

The general philosophy of climatic testing is to expose the test vehicle and its support equipment as much as possible to the environment, to utilize the vehicle on profiles approximating actual mission requirements, and to exercise all available subsystems and support equipment as thoroughly as is practical. Specific subsystems tests are usually integrated into the flight profile at points corresponding to their use in normal operational conditions. However, some profiles are flown to simulate the worst case that could reasonably be anticipated, and others are flown specifically to investigate problem areas or to evaluate corrective actions. Attention is directed toward establishing and verifying specific maintenance and operational procedures that may be required to counter environmental effects.

Flight testing has become extremely expensive, and acquisition program managers have real limitations on resources to conduct these tests. Initially in the development and evaluation process, the primary emphasis is rightly placed on airworthiness, structural integrity, performance, flying qualities, system capability, reliability, maintainability, and man-machine compatibility. Flight testing in extreme climatic conditions is nearly always the last testing done. When funds and time are limited, program managers look in this direction to cut costs. All too often all-weather testing is compromised or eliminated completely. Environmental capabilities may be designed into a piece of equipment, but it is quite difficult and very expensive to modify equipment that has already been built. This late testing means that many units have been constructed before environmental design deficiencies have been discovered and expensive retrofitting is the only solution. Consequently, in many cases the system will be deployed in its original configuration. When the problems are discovered in the field, expensive delays and loss of mission capability results. So, the bottom line is - pay me now or pay me more later.

We can place much confidence in the resourcefulness of our maintenance and flight crews to provide real-time workaround solutions for many problems. Today's highly complex weapon systems leave little latitude to improvise. North Atlantic Treaty Organization (NATO) security demands weapons that are as dependable as possible under all extreme climatic conditions.

Experience has shown the value of environmental testing for both weapon system and ground support equipment. By proper programming and support, a single test aircraft could furnish all the necessary baseline environmental information in approximately one calendar year. If the test period runs concurrently with the development flight test

program, environmental related modifications can be incorporated in the production line along with other changes resulting from a development program. This assures the availability of a globally effective system in the shortest possible time.

1.3 Test Content

An all-weather test program consists of climatic and adverse weather tests which are usually conducted in three phases. These phases are normally performed consecutively. A typical sequence would be as follows:

a. Climatic tests conducted under artificially controlled conditions.

b. Climatic tests conducted in cold arctic, hot desert, tropic, and adverse weather conditions.

c. Operational use and storage of systems during extreme weather periods in cold, hot and tropic environments.

Testing by the United States Air Force in a controlled environment is usually done in the McKinley Climatic Laboratory at Eglin AFB, Florida. In the United Kingdom, this type of testing is done in an environmental facility at the Aeroplane and Armament Experimental Establishment, Boscombe Down. Tests conducted in a controlled environment usually identify major problem areas, detect and resolve possible flight safety problems prior to deployment for flight testing at natural sites, obtain baseline data, and allow the development of workaround procedures. The primary advantage of testing in a controlled environment is that most climatic conditions can be controlled and maintained for an indefinite period of time. These tests provide useful inputs to the off-site operational climatic tests. Testing in a controlled environment has several inherent restrictions which include the following:

a. An aircraft cannot be taxied or transitioned from ground to flight operations, so some components cannot be exercised with airloads (e.g., landing gear and flight control systems).

b. Performance of all major systems cannot be completely tested (e.g., radar, communication/navigation, and environmental control systems).

Arctic testing is normally done during natural low temperature conditions, which are typical during the winter months at a location such as Eielson AFB, Alaska, or Cold Lake and Yellow Knife, Alberta, Canada. Hot desert testing is done under natural high temperature, high solar radiation conditions, which are typical during the summer months at the Naval Air Facility (NAF), El Centro, California, or the Marine Corps Air Station (MCAS) Yuma, Arizona. High temperature testing is conducted by the French Military Forces near the east coast of central Africa. Tropic testing is done under natural moderate temperature, high humidity, high moisture conditions, which are typical during the autumn months at a location such as Howard AFB, Panama.

Adverse weather testing is that testing conducted under simulated and actual weather conditions which are detrimental to the operation or performance of the system under evaluation. It includes corrosive environmental testing of systems under conditions involving atmospheric pollutants and/or natural corrosive processes. This type testing has been conducted by North Atlantic Treaty Organization countries (e.g., Denmark, Belgium, Norway, The Netherlands, United Kingdom, and the United States) in northwestern Europe.

Adverse weather tests of aircraft include the following:

a. Artificial and natural in-flight icing and rain.

b. Wet, slushy and icy runway/taxiway performance and handling qualities.

c. Freezing rain exposure.

d. Engine water ingestion on the ground and in flight.

e. Evaluation of Instrument Flight Rules (IFR) capability.

f. Evaluation of the effects of corrosive atmospheric pollutants.

g. Turbulent flight evaluation.

Cold arctic, hot desert, tropic and adverse weather tests are conducted at remote sites under natural weather conditions to exercise a complete weapon system in an operational environment and to test under conditions not possible in a laboratory. These tests are designed to simulate operational missions to provide data on weapon system and subsystem performance, and to verify and revise procedures and methods of operation as required to optimize system performance. Additionally, these tests stress evaluation of new components and subsystems and those that may have been previously identified as marginal or critical for extreme climatic operations.

The environment obviously cannot be controlled during deployments to natural test sites. Normally, there is only a short time available for test accomplishment. If the extreme conditions are not experienced in a given season, it probably will not be possible to repeat the test until the following year. Therefore, every effort must be made to obtain the maximum amount of valid data in the shortest possible time. This task requires a significant amount of planning, a viable instrumentation system, and adequate qualified manning. Typical test time for exposure to climatic extremes of a given area are shown in Figure 1.

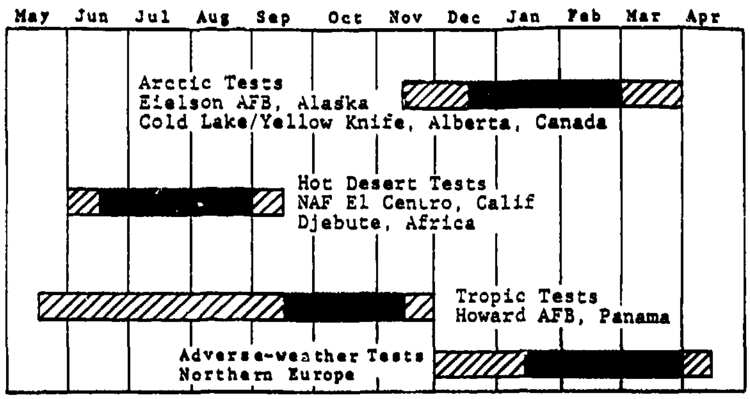


Figure 1 Climatic Extremes Windows

Notes

1. Conditions desired for adequate climatic tests are as follows:
   Arctic: -20 Deg F (-29 Deg C) and below
   Hot Desert: 110 Deg F (43 Deg C) and above
   Tropic: 80 Deg F (27 Deg C), Relative Humidity 75 Pct and above

2. Shaded areas denote prime test time. Cross-hatched areas denote marginal test time.

Separate qualification testing of individual components and subsystems is not normally considered a part of climatic testing. It is assumed that this qualification testing has previously been conducted by the equipment manufacturer, in response to acquisition program management. Past experience has shown that qualification testing at a subsystem level is not adequate to define operational capabilities, procedures, and limitations of the complete system, mainly because the interface between systems has not been evaluated. Qualification test data can be used to supplement total systems data to determine proper performance during climatic extremes.

Qualification of military equipment through similarity to commercial aircraft applications is often attempted. However, this similarity usually does not assure reliable all-weather operations at the climatic extremes required of some military weapon systems. Insidious problems could be introduced by accepting commercial aircraft subsystems or components on a similarity basis, which do not satisfy military specifications or operational requirements (e.g., the lubricants used in sealed bearings, standard size tolerances and materials).

Operational test and evaluation at extreme climatic conditions should normally be conducted by the using command concurrently with or immediately subsequent to development, test and evaluation and should continue after the air vehicles are operational. If possible, more than one vehicle should be tested. As a minimum, these evaluations should be done in climates normally encountered in day-to-day usage of the equipment. Storage of equipment may involve special procedures.

2. DIRECTIVES AND REGULATIONS

Review of the applicable regulations, military standards, and air vehicle specifications is necessary prior to preparing a detailed test plan for ground and flight testing under extreme environmental conditions. The air vehicle design specifications provide most of the detailed information on climatic conditions/extremes for which a particular air vehicle was designed. Frequently, the design specifications reflect requirements of earlier versions of military standards. This information has to be supplemented with assumptions based on known operational requirements. The following paragraphs discuss the primary United States Air Force regulations and standards as they pertain to all-weather testing.

2.1 AFR 80-31, All-Weather Qualification Program for Air Force Systems and Materiel

AFR 80-31 (Ref 2), including Air Force Systems Command Supplement 1 (Ref 3), is the primary authority for all-weather testing. It states that the United States Air Force must have the capability to conduct operations in all types of environmental conditions. Additionally, it states that effects of the natural environment must be considered in the design, development, testing, and procurement of systems or material which may be operated, maintained, stored, packaged, and transported under a wide range of natural environmental conditions. This regulation outlines the five categories of all-weather testing, and other subjects, which include design criteria, policies for all-weather testing, assignment of responsibilities, and special test support procedures.

2.2 MIL-STD-210, Climatic Extremes for Military Equipment

MIL-STD-210 (Ref 4), establishes uniform climatic design criteria for military material which is intended for worldwide use. It does not apply to design of material to be used only in specific areas or environments. Extreme climatic conditions contained in this standard apply broadly to all items of equipment and systems and generally represent the extreme conditions which usually constitute the minimum acceptable conditions. When it is known that the equipment or system will encounter conditions different from the environmental levels stated in this document, the limits should be modified by the equipment or system specifications/contract.

MIL-STD-210 presents criteria for:

a. Ground environment.

b. Naval surface and air environment.

c. Worldwide air environment.

Each of these environments contain the high and low extremes of climatic conditions which include; temperature, absolute and relative humidity, windspeed, rainfall rate, blowing snow, snow load, ice accretion, hail size, sand and dust, and radiation. Additionally, MIL-STD-210 presents tables of diurnal cycle data for temperature and other elements associated with the extreme climatic conditions for ground operations.

2.3 MIL-STD-810, Environmental Test Methods

MIL-STD-810 (Ref 5), establishes uniform environmental test methods for determining the resistance of equipment to the effects of natural and induced environments peculiar to military operations. This MIL-STD is complex and has very broad applications. It provides environmental test methods designed to obtain, as much as possible, reproducible test results. When it is known that the equipment will encounter conditions more or less severe than the stated environmental levels, the test may be modified by the equipment specification. This MIL-STD is generally used for component or equipment qualification testing. These procedures are not usually applicable to weapon system testing, however, in some cases MIL-STD-810 methods may be modified and used in accomplishing laboratory tests of the overall weapon system.

MIL-STD-810 presents a recommended test sequence for the numerous test conditions and test methods including; temperature, altitude, g-levels, vibrations, cycling period, acoustic levels, solar simulation, gunfire, and humidity.

3. PROGRAM PLANNING AND CONDUCT

Successful completion of the objectives of an all-weather test depends on how thoroughly the planning has been accomplished. In addition to the technical aspects, close attention needs to be paid to the safety aspects to preclude mishaps during the tests. Testing under extreme climatic conditions has its own unique set of technical and safety considerations.

3.1 Test Planning and Procedures

The primary role of the climatic test engineer, at this stage, is to determine in what conditions a given air vehicle should be tested, the types of tests to be conducted, and to prepare a schedule such that tests in those environmental conditions are attained. The instrumentation and data acquisition requirements also need to be assessed.

Initial test planning for evaluating a major weapon system in extreme climatic conditions should normally begin two or three years prior to the start of active testing. Very general test concepts are prepared initially, (e.g., outlining test phases, approximating test/flight hours, etc.) followed by more detailed and specific plans as more information is obtained on the equipment to be tested.

After the conditions under which the weapon system will be tested have been determined, a detailed test plan should be developed for each specific subsystem to be tested. These test plans will normally be written by the engineer responsible for that specific subsystem. When possible, these subsystems engineers should be sent to the remote sites to participate in the conduct of the tests, under the technical supervision of the climatic test engineer.

The individual test plans should be incorporated into an integrated test plan for each of the test sites by the climatic test engineer. This plan ties all activities and events together, which details how all objectives will be achieved. The test plans must be in sufficient detail to permit test procedures to be prepared for either Climatic Laboratory or remote site climatic tests (e.g., objectives, flight conditions, ambient conditions, instrumentation, and data required). To do this, the items to be developed by the climatic test engineer with the assistance of subsystem engineers, and will include the following:

a. A temperature versus calendar-time profile for Climatic Laboratory tests, if they are to be accomplished. A typical temperature profile used during a Climatic Laboratory test is presented in Figure 2.

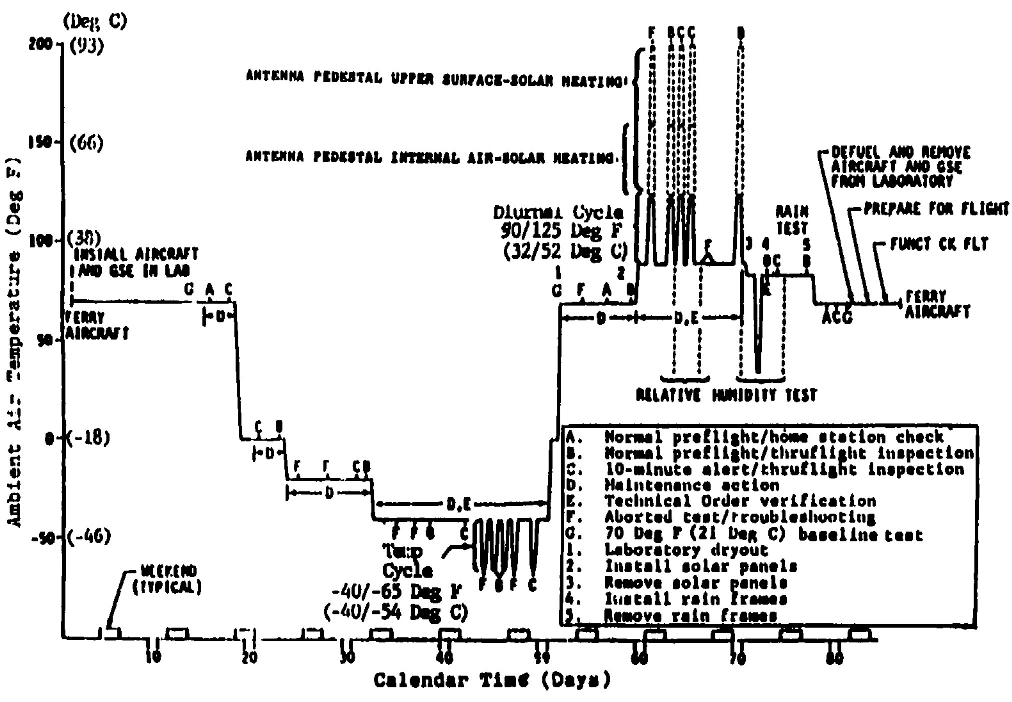


Figure 2 Typical Climatic Laboratory Test Temperature Profile

b. Type of tests to be conducted (e.g., normal pre/postflight, scramble starts, and mission scenarios).

c. Number of tests to be conducted at each test condition.

d. Schedule for climatic tests so that climatic "windows" can be attained.

e. Instrumentation measurement list to include sampling rates and required accuracies.

A technical support plan should be prepared which details the support required for the climatic tests. The climatic test engineer must provide supporting agencies with an outline of the services required (e.g., photo and data requirements, instrumentation calibrations, etc.). These requirements must be estimated on a mission-by-mission basis for the entire program. Careful attention to this planning phase is required to ensure support will be available for the climatic tests when required. Other services to be provided by the host must be considered separately (e.g., billeting, meals, and transportation).

The climatic test engineer will integrate detailed test procedures using the overall test plan to determine the order and extent of each test. These procedures define the operational subsystem tests and are developed using current operational technical order procedures. An effective method for establishing the combined procedures for each test run is to develop a task versus climatic condition matrix. A typical matrix for the Climatic Laboratory is presented in Table 7 of the Appendix, Section 8.3. This matrix was constructed by combining all the tasks detailed in the integrated test plan for each test condition. This matrix is considered absolutely essential and can be used to track objectives accomplished and to provide a basis for report preparation. The main use, however, is to minimize the effort for establishing combined test procedures for a given test run.

Using aircrew and ground crew checklists as a framework, the basic test procedures are developed into test run sheets for the Climatic Laboratory, or test cards for natural site flight test missions. The combined test procedures consist of the basic checklist procedures with any special or repeat tests interspersed. Development of these procedures should be a joint effort with aircrew and maintenance personnel to ensure fidelity to an operational situation.

Procedures for the Climatic Laboratory should be developed so that minimum modification of aircraft subsystems and instrumentation will be required for the other test sites. Whenever possible, the tests in the Climatic Laboratory will be conducted following technical order procedures for functional evaluation of subsystems, components, and ground support equipment. These procedures should encompass all applicable procedures from preflight through postflight, including those for alert. Validation or verification of selected extreme weather operational technical order procedures can be accomplished in conjunction with these tests. Tests conducted at the other deployment sites will contain most of these same tests integrated into mission scenarios during actual flights. Technical order procedures should be modified when they prove to be inadequate and workaround procedures should be developed and documented. The test procedure cards for a given test organize the test points in proper sequence with the crews' checklists and contain all instructions to enable the test conductor and the test pilot/crew to accomplish the test. Whenever possible, alternate test procedure cards should also be prepared and briefed. Then, if a primary test cannot be conducted for some reason, an alternate test might be substituted with minimum impact.

A mission briefing is conducted prior to the start of the day's activities. The test conductor, test pilot(s)/crew, test engineer(s), instrumentation engineer, maintenance supervisor, crew chief, Laboratory personnel and any additional key personnel should be in attendance. During this briefing the test activities, including the alternate tests, are presented in detailed step-by-step sequence to ensure complete understanding of the test procedures and requirements by all concerned. The major portion of the briefing is presented by the test conductor. The test pilot will brief weather and any pertinent operational factors; the crew chief will brief the status of the weapon system and describe any discrepancies; the instrumentation engineer will brief the status of the instrumentation, etc.

A debriefing should be conducted as soon as possible after completion of each mission or Climatic Laboratory test to record the results of everyone's observations and experiences during the test and to ensure understanding of the problems encountered. The same participants that were in the pretest briefing should be in attendance plus any specialists required. The test pilot should discuss the mission in detail. The maintenance status of the test vehicle should be discussed, and any maintenance actions required prior to the next test should be outlined. The maintenance status should be outlined as early as possible so the maintenance personnel can expedite their corrective actions and get the weapon system ready for the next test with minimal impact on climatic conditioning. Extent and quality of test data gathered (e.g., cold, hot soaks, etc.) should be assessed, procedural changes/improvements implemented and an assessment made of objectives achieved. This assessment sets the stage for preparation of the procedures for the next test. Reliability and maintainability forms and Human Factors Test and Evaluation questionnaires should be completed during the debriefing.

All aspects of the mission and weapon system status should be discussed and pertinent information documented during the meeting. Originals of all data and forms should be filed for future reference.

3.2 Instrumentation and Data Acquisition

Adequate data acquisition is essential for the conduct of a thorough climatic test program. Environmental parameters (temperature, humidity, solar radiation, rainfall, etc.) must be documented to define climatic conditions during the tests. Extensive temperature/pressure instrumentation along with key operating parameters should be installed within the test vehicle subsystems to track subsystems condition during testing, document environmental conditions in case of failure, help in fault analysis, and aid in determining any corrective action or modification required as a result of subsystem or component failure. This information is also useful to designers of future systems through accurate knowledge of present subsystem performance during extreme environmental conditions. The instrumentation engineer should prepare an instrumentation requirements document which details instructions for installation and operation of instrumentation. Airborne data acquisition, with quick-look data reduction capability, Climatic Laboratory systems, and weather recording are the primary systems available to the climatic test engineer.

3.2.1 Instrumentation Parameters

Subsystem instrumentation may vary from 20 to over 300 parameters depending on the complexity of the test vehicle and/or subsystem under test. Engine oil temperatures and pressures, hydraulic system temperatures and pressures, and fuel temperatures and flow rates are typical examples of instrumented parameters. Selection of specific instrumentation parameters is based on past climatic test experience and particular engineering requirements determined for the specific weapons system to be tested. A generic instrumentation parameter list for all-weather testing is contained in Table 6, Section 8.2, of the Appendix.

Selection of parameters to be recorded is a responsibility of primary importance to the climatic test engineer assisted by subsystem engineers. The test vehicle systems should be properly instrumented before deployment since addition of parameters in the field is very difficult, costly, and time-consuming. It is extremely difficult to install sensors so that they do not impact the function of the item being measured. Also, each parameter is initially very expensive and the total number must be kept to an absolute minimum from the standpoint of objective accomplishment, and system complexity. Because it is not feasible to instrument every conceivable item, compromise is the rule. Subsystems with histories of problems and those with marginal qualifications should be of prime interest (e.g., hydraulic systems nearly always leak at extremely low temperatures). The airframe manufacturer usually has many parameters identified and designed for installation on several test vehicles. The climatic test engineer must review these parameters and correlate them with parameters required for the weapon system under test. It is best to use the airframe manufacturer specified parameters, where possible. The reasons are:

a. An already designed transducer installation saves time and money.

b. Direct data correlation is possible between identical transducers/locations on the climatic and airframe manufacturer test vehicles. When the airframe manufacturer has not designed a parameter corresponding to a necessary climatic requirement, the type and location of the transducer must be specified sufficiently to enable proper design and installation.

c. There is a high probability that manufacturer installed instrumentation was designed to minimize the impact on system performance.

Consideration should be given to parameters required to determine mass temperatures during (soak) periods. These parameters would be used to determine thermal stabilization. These temperature sensors are usually installed near the onboard system parameter sensors. In the Climatic Laboratory these parameters can be read out on the Climatic Laboratory Instrumentation System without power applied to the onboard systems. Typical mass temperatures would be the hydraulic fluid reservoir, engine oil reservoir, main fuel cell, and large internal metal mass.

In addition, ambient air temperatures should be obtained near the extremities of the test vehicle, especially large aircraft, and should include, as a minimum, the vehicle nose, tail, tip of vertical stabilizer, wingtips, and wheel well area. In the Climatic Laboratory these temperatures will be used to control the Laboratory conditioning to ensure the same soak temperature for the entire test vehicle.

3.2.2 Airborne Test Instrumentation System

The basic airborne instrumentation package consists of transducers, commutators, signal conditioning, (i.e., analog-to-digital conversion), power supplies, tape recorder, and controls. The equipment may be installed on an internal pallet or in an external pod, depending on space availability. The instrumentation package may be designed and installed by the test organization or the airframe manufacturer. When equipment bays are utilized, the airframe manufacturer will normally determine hardware location, design the mounting and install the equipment. The unit size and power

requirements are detailed to the airframe manufacturer, who is responsible for overall compatibility and operation of the instrumentation system. The airframe manufacturer is normally responsible for installation of all transducers and wiring to the instrumentation package. The specifications used by the United States Air Force for installation of instrumentation are contained in AFSC Regulation 80-33 (Ref 6). Detailed instructions and deviations to the specifications should be included in an instrumentation requirements document. The instrumentation engineer is responsible for monitoring installation, operation, and maintenance of the system. These activities should also be monitored by the climatic test engineer.

The test organization or the airframe manufacturer will normally design the installation of transducers called for in the instrumentation requirements document. The climatic test engineer should review the design drawings for each transducer to see that they are acceptable from the climatic test standpoint. Care should be taken to ensure that:

a. Temperature transducers are located in a free flowing fluid area. Location in a standpipe or isolated area may give inaccurate indications.

b. Temperature transducers are not located too close to heat sources outside the area of interest.

c. Transducer ranges are large enough to record the extremes anticipated during test.

d. The frequency response of the pressure transducers is adequate.

The instrumentation system should have the capability to withstand environmental extremes. Extremely low temperatures have proven to be the most critical environment and it may be necessary to provide heating for instrumentation components. Localized, low level heating with insulation to prevent heat transfer to adjacent subsystems will minimize any effect on the systems under test. Whenever possible, any heating or cooling requirement should be identified at an early stage to allow incorporation in the basic instrumentation design.

Instrumentation controls, event, and time correlation devices should be installed in the cockpit area. The time readout should be installed on the forward instrument panel area for easy visibility. Controls should be easily accessible. It may be necessary to sacrifice a production control panel to mount instrumentation controls, as well as some production subsystems components to install the instrumentation package. Tradeoff of production subsystems must be carefully evaluated with the subsystem having the least environmental impact being the best choice for deletion. To facilitate data correlation, synchronized time readouts should also be located in the test booth during Climatic Laboratory tests, and in the control room during other deployments.

Provision must be made for removal of the data acquisition system, recorder, and controls during Climatic Laboratory tests. The instrumentation system must be capable of operation with these components removed from the test vehicle and located in an air-conditioned booth. This minimizes climatic effects on critical items of instrumentation and increases reliability and ease of maintenance, important factors from a cost and schedule standpoint in the expensive laboratory environment. The instrumentation system must also operate independently of test vehicle power so that data can be obtained without operating the test vehicle engines.

A similar method of instrumentation operation is necessary to conduct the 72-hour heat soak and to acquire soak data prior to each flight test during climatic deployment for the hot desert test phase. The test objective is to acquire periodic internal temperature data usually at one-hour intervals. To ensure reliable operation, the data acquisition system should be placed in an air-conditioned area and be provided power independent of the test vehicle. The test vehicle internal temperatures during ground heat soak could reach levels high enough to cause the magnetic tape to stretch and damage the emulsion during recorder operation. Opening the test vehicle for tape loading access will also interrupt the desired heat soak.

The airframe manufacturer is often tasked to deliver a functioning instrumentation system with the test vehicle delivery. Acceptance of this system normally occurs concurrently with acceptance of the test vehicle. The instrumentation engineer has primary responsibility for acceptance of the instrumentation package. However, the climatic test engineer shares responsibility in the delivery of an acceptable system. Two or three test flights are usually required for acceptance of the test vehicle and instrumentation. The climatic test engineer should participate in preparation of acceptance flight test cards for these missions. Test cards are prepared in a command-response format and should contain step-by-step procedures which will exercise all subsystems to insure proper operation of installed transducers. All instrumentation control functions should be exercised to insure proper operation. Proper functioning of the transducers is determined by an analysis of the data. This may be accomplished by using the quick-look station, or a data reduction facility. All instrumentation discrepancies should be corrected prior to acceptance. Subsequent repair/redesign in the field is to be avoided whenever possible.

3.2.3 Transportable Data Processing System

A real-time/quick-look system should be made available to display or record portions of the data tape for real-time (Climatic Laboratory) or quick-look (postflight data tape playback after remote site test missions) analysis of vehicle subsystems, as required. The real-time/quick-look system used by United States Air Force test engineers was a digital-to-analog converter with up to five strip chart recorders for analog strip out of up to 40 key parameters. Time of day was dubbed on the data tape, displayed using a time-code translator, and recorded on the strip chart paper along with test data. In the Climatic Laboratory, the system was used real time in the test control booth. The test engineers hand annotated the strip charts at appropriate points such as engine start and flight control cycles, for postflight analysis and data plot selection. At other remote sites this system could be used for postflight playback in the the same manner as used in real time at the Climatic Laboratory. The converter had cathode ray tube data display capability, which was used to determine if all parameters were within limits and functioning properly. The test engineer reviewed the strip chart data and spot-checked the aircraft systems for suspected trouble areas. He determined start and stop times and data plot groups required to define subsystem operation during events such as auxiliary power unit and engine start, flight control warm-up and landing gear retraction, to be subsequently plotted using a data processor.

A portable data processor should be made available at the test site to process and plot portions of the data tape in report quality form. The processor most recently used by United States Air Force engineers consisted of a computer coupled to a digital-to-analog converter. An airborne tape recorder was used in the playback mode to feed data into the converter. Time was displayed so the computer operator could time search the tape. Data were tagged and sent to the computer, where engineering units conversion took place. A printer-plotter was used to generate data plots. After performing the real-time/quick-look analysis to determine which events and data plots were required for these events, the test engineer had the data tape played back on the portable data processor. The computer did the required computations, converted the data to engineering units, and drove the plotter to produce final report quality data plots.

The real-time/quick-look system and the portable data processor components were packaged to either be airlifted with other support equipment or shipped via normal surface transportation methods to the test site.

3.2.4 Ground Support Unit

A ground support unit has been developed for preflight and postflight maintenance of instrumentation at the air vehicle. The operational functions of the ground support unit, controlled by a computer, are to decommutate, display and list output data. The ground support unit is also used to load the system control unit format memory. Software routines are available for a diagnostic analysis. Other components of the ground support unit include: a two-cartridge magnetic tape unit, keyboard, printer, bit synchronizer, frame synchronizer, system controller and temperature environment controls.

3.2.5 Climatic Laboratory Instrumentation System

A centrally located digital computer based plant surveillance, control, and data acquisition system serves the Climatic Laboratory and the testing agencies using the facility. Operators of the plant environmental simulation and control systems rely upon the Laboratory instrumentation system for real-time display of related parametric data. Test environments are monitored and the data processed for display and recording. The primary uses of this system by the test team are to monitor thermal stabilization and to back up the test vehicle data system.

An important requirement for Climatic Laboratory tests is to assure that the test vehicle components stabilize at, or closely approach, target temperatures. This requires close monitoring of selected subsystems during the soak period. Selected temperatures may be connected through the Laboratory system for around-the-clock monitoring and recording. Care should be taken when selecting thermocouple locations for measurement of bulk fluid or large metal mass temperatures. Externally located sensors may not be accurate due to stratification. However, insulating the transducer helps alleviate this problem.

Transducer outputs can be fed simultaneously to the test vehicle and Laboratory instrumentation system. This ensures collection of valid data in the event of test vehicle instrumentation system failure. Software required for recording test vehicle data (e.g., mass temperatures) is provided by the Climatic Laboratory. Software for processing test item data can be provided by the Laboratory or by the user.

The Climatic Laboratory instrumentation section is equipped to provide calibrations and maintenance of permanently installed facility instrumentation and control equipment. This section is also equipped to provide limited calibration of instrumentation parameters in support of tests. Pretest planning with Laboratory hardware and software personnel is essential if their instrumentation system is required in support of a test program.

The Climatic Laboratory instrumentation system has a total of 400 channels available for test item data, with a maximum sample rate of 25 samples/second on each

channel. The test item input to this system is required to be 4 to 20 milliamperes. The Laboratory maintains a variety of voltage/current transducers to accommodate electrical signals from test instrumentation sensors. The overall accuracy of recorded data should be within ±0.5 percent of full range.

The user will normally be required to provide instrumentation from which the Laboratory system can accept analog voltage signals for transmission to the multiplexer and conversion to digital form for recording on magnetic tape for processing. The conditioned data can also be displayed in engineering units at a computer display terminal located at selected key places within the Laboratory complex. The quantity of real-time data which may be displayed is limited to 8 to 12 parameters (including time) and must be established at pretest planning sessions. Multipoint strip chart recorders are available at the Climatic Laboratory as well as oscillographs and other analog recording devices for applications where use of the instrumentation system is not appropriate.

The engine and equipment test cell is equipped with specialized engine test instrumentation. This is dedicated instrumentation which serves to provide the essential monitoring and displaying of data associated with engine performance evaluations and qualification tests. Signals from this instrumentation can be input to the computerized data system.

3.2.6 Weather Recording System

The actual environment to which the test system is exposed must be recorded to document test conditions. During deployment to remote test sites, weather services and individual pieces of weather instrumentation have been used to gather this data. Since manual data recording and reduction from individual instrumentation sensors is too time consuming, a portable, automatic recording weather station is essential to achieve the required accuracy and shorten data reduction time. A detailed description of a typical system and the range, resolution and accuracies of its parameters can be found in Ref 7.

This system records parameters in standard teletypewriter code and format at rates from one sample per second to one sample per day. Sampling rate can be set for two samples per hour under normal circumstances. Standard data includes wind direction, wind velocity, ambient air temperature, relative humidity, barometric pressure, precipitation rate, solar radiation, date and time of day.

During testing, the weather station should be located as near to the test vehicle as possible, consistent with safety, (e.g., out of engine blast, allowing taxi clearance, etc.) but not influenced by proximity to a building. When possible the unit should be powered by dropline from hangar power. General utilization at the various climatic remote sites is as follows:

a. Climatic Laboratory Phase

The weather station is not used in the Climatic Laboratory since this type of instrumentation is provided. A separate calibrated pyrheliometer may be used to record solar radiation as required during the Laboratory tests.

b. Arctic Phase

Ambient temperature near the parked test vehicle is the prime weather parameter. Wind velocity, wind direction, barometric pressure and relative humidity should also be recorded to document test conditions.

c. Desert Phase

Solar radiation and ambient temperature are the primary measurements required to document conditions during hot desert tests. Wind velocity, wind direction, barometric pressure and relative humidity should also be recorded to document test conditions.

d. Tropic Phase

Primary weather sensors to be utilized during the tropic tests are relative humidity, precipitation, ambient temperature, wind direction and wind velocity.

3.2.7 Photographic Documentation

Photographic documentation of off-site testing is an important aspect often overlooked during the test program. Photography is an important tool in engineering analysis of events occurring in the course of the tests. Obtaining documentary photographic coverage is a program management responsibility. It provides a vivid portrayal of the test activity to management, and is useful when preparing future tests. Since it is closely allied with engineering photo requirements, the climatic test engineer should actively participate in obtaining this type of information. Black and white stills, color stills, 16mm color motion picture, and color video are the primary types of documentation required. The availability of remote site photographic support varies from site to site and time to time. If the availability of desired support is doubtful, it is best to take a photographer with the test team to ensure proper test

documentation. The primary use of black and white still photography is for documentation of failures. Prints of each photograph are required for reporting specific deficiencies. These photos are also very useful for amplifying discussion in the technical report. A photograph can illustrate an accessibility problem or damage much more concisely than descriptive verbiage. It is much better to have too many photographs and discard some, than to realize that a necessary photograph is not available for a report.

Sixteen millimeter color motion picture and color video coverage is primarily used to document tests in progress. It is obtained on the ground and/or from a photo-chase aircraft as appropriate. Documentary coverage should be discussed with photographic personnel who are experienced in the process (e.g., layouts, sequencing, etc.). Although technical requirements for color motion picture or video coverage are limited for most climatic test applications, valid needs do arise, such as circulation of snow or sand, during a helicopter approach and landing, and required maintenance crew activities.

3.3 Types of Tests Conducted

Virtually all subsystems on a weapon system as well as man-machine compatibility should be evaluated during testing in extreme climatic conditions. During the planning phase, test requirements should be established by specific engineers and scientists in each area of expertise. These tests should be conducted under all possible types of operational scenarios (e.g., normal, alert, and daily preflight and postflight, as applicable). Instrumentation and aircrew comments and questionnaires are used to evaluate system performance.

3.3.1 Propulsion System

The general objective of these tests is to evaluate the starting and operating characteristics of the auxiliary power unit and engines. This includes evaluation of initial engine oil pressure and oil consumption, engine water ingestion, and engine icing. The auxiliary power unit and engines should be started using each of the available methods for starting (e.g., ground cart, engine bleed air, and auxiliary power unit shaft power). The start should be considered successful if the engine starts, accelerates to idle and stabilizes within a specified time period without exceeding the turbine temperature limit. Any unsuccessful start should be attempted again if engine limits have not been exceeded.

Steady-state and transient engine operations should be tested at all conditions. The objective of these tests is to evaluate the propulsion system during fixed engine operation (idle, intermediate, and minimum and maximum afterburner), and transient engine operation (idle to intermediate and idle to maximum afterburner). Successful operation will be characterized by stable engine functioning with engine parameters within operating limits, and acceleration/deceleration time limits. Throttle transients should be executed slowly at first, then within the shortest allowable time.

After engine start and prior to initiating tests, the engine access doors should be opened and a visual inspection conducted of all fluid lines, fittings, and components for leakage, especially during cold temperature tests. Engine oil consumption and metal content characteristics should be evaluated during these tests. The engines should be fully serviced prior to testing. The oil service cart used should remain at the same ambient conditions as the aircraft to maintain overall test integrity. The engine's capability to ingest water up to the specification limit should be evaluated at the appropriate climatic conditions. Engine operation will be considered successful if the engine remains stable (no stalls or combuster blowouts) and demonstrates proper operation at the specified conditions.

3.3.2 Environmental Control System

Environmental control system tests include evaluation of proper conditioning of the cockpit and other flightcrew areas, cargo compartments, avionics, stores, and evaluation of secondary pressurization. Tests should be conducted using engines, auxiliary power unit, and support equipment for air sources. It is desirable to have a hand-held pyrometer during these tests to measure surface and air temperatures at selected locations.

Crew compartment conditioning should be evaluated during engine operation. The specific objectives would be to evaluate:

a. The capability of the environmental control system to automatically maintain crew and cargo compartment ambient temperature within specified limits.

b. The capability of the environmental control system to prevent stratification of temperature.

c. The capability of the separate crew station and cargo compartment temperature controllers to satisfactorily regulate ambient temperature.

d. The capability of the environmental control system water separators to remove moisture.

e. Crew compartment noise levels due to environmental control system operation.

f. Whether crew area touch temperatures exceed specified limits.

g. The windshield defogging/defrosting system performance in both the normal and alternate modes.

The stores refrigeration unit should be evaluated to determine if it can provide conditioned air at sufficient flow rates and temperatures, and remove visible moisture from conditioned air. The capability of the liquid avionics cooling and air recirculation coolant loops should be evaluated to determine if these systems have the capability to maintain steady state temperature of the coolant supplied to the crew station and avionics bays within specified limits. In addition, the functional adequacy of the bleed air secondary pressurization system should be evaluated to determine if it meets specified requirements.

3.3.3 Fuel System

Fuel system testing includes evaluation of ground refueling and defueling procedures, transfer, cooling loop, venting function, and center of gravity control system operation. The overall objective of fuel system tests is to determine whether the system functions properly at all conditions both on the ground and in flight. The specific objective of ground refueling/defueling tests is to evaluate flow rates, and technical order procedures. Single point refueling/defueling should be evaluated at all climatic conditions tested. Fuel transfer rates and ease and practicality of technical order procedures should be evaluated. Problem areas such as poor access or leakage should be identified and workaround procedures developed as necessary to perform the required tasks.

Evaluation of the venting system to allow for fuel expansion is conducted at high ambient temperature conditions. The test vehicle is loaded to the maximum fuel quantity allowed. Any fuel vented should be collected and measured. The test vehicle should be inspected to determine if vented fuel has collected in cavities.

When fuel is used for a heat sink in the test vehicle, fuel cooling loops are evaluated to determine the fuel heating rate for extended engine operation at high ambient temperatures or during high speed low level operations. The air vehicle should be filled to capacity and the engines operated as required for extended ground idle, taxi, takeoff and low level flight at high speed.

The fuel system should be evaluated for susceptibility to leaks and valve malfunctions during exposure to extreme climatic conditions. Inspections of the system should be conducted before and after each test. The cockpit fuel management panel and indicators should be used to monitor fuel tank quantities and center of gravity.

3.3.4 Hydraulic System

The functional adequacy of the hydraulic system should be evaluated by monitoring operating system temperatures and pressures and the proper function of hydraulically-powered components at all required conditions. Reservoir and system pressurization should be evaluated using both primary (engine) and secondary (auxiliary power unit) power. The hydraulic fluid-to-fuel heat exchangers should be evaluated for effectiveness at high ambient temperatures. The auxiliary power unit start system and the hydraulically powered emergency electrical generator should be tested, and flight control checks performed, with particular emphasis on performance at low ambient temperatures during alert conditions. System servicing and potential for leakage should be evaluated at all conditions tested, and workaround procedures developed, as required. The capability of the hydraulic power supply system to provide sufficient pressure, during simulated worst case loading conditions, (e.g., normal and alert takeoffs) should be evaluated. The hydraulic system should be monitored during auxiliary power unit and engine starts to determine if the temperatures and pressures stay within specified limits. During engine start, with the auxiliary power unit running, the hydraulic pump outlet pressures should be monitored to determine if the pumps are cavitating and if they automatically depressurize to aid engine starting.

The hydraulically powered flight controls should be cycled in all three axes to full deflection as rapidly as possible prior to takeoff. The pilot should hold the control at full displacement until the control surface reaches maximum deflection, or stops moving. If the specified no-load surface rates are not achieved, the surface should be cycled until the required rates are reached. Flaps, slats, overwing fairings, and wing sweep should be cycled prior to takeoff to determine if the specified surface deflections are achieved. If acceptable flight control surface deflections or rates are not obtained, workaround procedures (e.g., control cycling, applying local heat, etc.) should be developed and tested to ensure sufficient control authority prior to takeoff. After takeoff, the flight controls should be cycled, while simultaneously raising the landing gear, retracting flaps and sweeping the wings, to determine if control authority is maintained.

Nosewheel steering should be evaluated in a cold environment to determine if sufficient deflections and rates are provided for safe ground operations. The deflections can be used to determine minimum turning radius. Brakes should be

evaluated during taxi operations. During each brake actuation and subsequent release, brake puck movement, return spring movement, wheel rotation, and brake pressure should be monitored.

Testing in the Climatic Laboratory before test flights in the actual environments should evaluate all modes of landing gear operation (e.g., normal and emergency). At low temperatures in particular, abnormal retraction (or extension) should be noted and analyzed for possible performance degradation during takeoff and climbout. Improvements in the landing gear subsystem may be mandatory before undertaking flights in the arctic. The landing gear should be retracted and extended after takeoff using the alternate extension system as well as the normal system.

Weapons bay doors, rotary launcher, and the aerial refueling receptacle should be exercised to determine their functional adequacy. The hydraulically powered electrical generator should be operated to determine if it produces the correct voltage and frequency.

Every mode/feature of hydraulically operated cargo access subsystems of transport aircraft should be exercised and the cause of any abnormal operation ascertained. Proper functioning of locks for clamshell or petal doors, nose visor openings, and pressure doors that serve as ramp extensions or rotate out of the way for airdrops should be assured. Dimensional variations due to exposure to extreme temperatures can cause some to fail to completely lock or unlock.

3.3.5 Electrical System

The overall objective of electrical system tests is to evaluate proper function at all required conditions. The electrical power generation and distribution system should be evaluated to include tests of the integrated drive generators, emergency generators, batteries, and bus distribution systems. Primary generator function should be evaluated using both auxiliary power unit and engine power to determine their capability to provide electrical power within design and specification limits. The electrical system also requires evaluation to determine whether it can provide uninterrupted power within design limits during transition between ground, auxiliary power unit-driven, and engine-driven generator power. To do this, performance of the generators should be monitored during auxiliary power unit start, paralleling of the auxiliary power unit-driven generators, transfer to engine-driven generator operation, and paralleling of each generator with the others.

The ability of a fully loaded primary engine-driven generator to provide power should be evaluated. In addition, the function of the direct current power supply system to provide power at all conditions tested should be evaluated. This system should be monitored for proper operation. The batteries should be monitored closely, especially at cold ambient temperatures, to determine whether they will provide sufficient power to accomplish alert auxiliary power unit starts. If they fail, workaround procedures may have to be developed. The batteries may have to be removed during soak periods at extremely cold ambient temperatures of 0 degrees F (18 degrees C) and below. The frequency and voltage output of the emergency generator and the essential bus should be monitored for correct operation during simulated primary generator failure. The constant speed drive should be evaluated to determine if it has the ability to maintain constant generator speed, and therefore frequency, during engine throttle transients. The constant speed drive decoupling mechanism should also be evaluated for proper operation.

3.3.6 Airframe System

The overall objective of these tests is to determine if the airframe adequately supports all systems, and is easy to maintain. The airframe should be inspected prior to start of any testing in extreme climatic conditions to establish a baseline condition. After exposure to appropriate adverse weather conditions, selected portions of the airframe should be inspected for trapped water or ice, corrosion potential, deteriorated surface finishes, cracked or delaminated seals or transparencies, deterioration of plastic, and damage to bonded honeycomb or composite structures.

The resistance of the airframe to water intrusion should be evaluated after windblown rain exposure. Where allowable water intrusion has occurred, the adequacy of drainage should be evaluated. After a freezing rain, areas should be identified where ice accumulations on or within the airframe may result in equipment malfunctions, damage to movable surfaces, foreign object damage to engines, or water in compartments after the ice has melted. Deicing procedures should also be evaluated during this time period. The landing gear should be inspected for ice accumulations that could prevent proper gear and door operation. After any potentially damaging accumulations have been removed, a test of the system for normal operation should be performed. Protective covers should also be inspected.

Special attention should be paid to windscreen cleaning, deicing, and rain removal. Any dulling, scratching, bubbling, delamination or cracking should be documented. The electrical, mechanical or gravity function of the crew ladder should be evaluated. The ladder should be exposed to freezing rain and icing to evaluate the non-slip surfaces.

All inflatable seals should be evaluated. Crew hatches, overwing fairings, and access panels should be exercised. Any specialized materials should be evaluated for deterioration or damage after exposure. As a minimum, inspections should be performed before the start and at the conclusion of testing. One frequent source of seal damage has been the mechanical removal of accumulated ice and snow.

Where hybrid structures (e.g, graphite, boron, Kevlar, epoxy matrix or fiberglass) are used, the vehicle should be inspected for damage or delamination. Where radar absorbing material is used (radome panels, engine inlets), any coating, bubbling, peeling or separation should be noted. The inlet radar cross-section vanes should be inspected for anti-icing heater blanket bubbling or debonding. Fiberglass engine inlet liners should be inspected for cracking and material separation. Any damage to the radome structure should be noted. Where plastics are used, (e.g, panels, cockpit and equipment bays) cracking or softening and deforming should be noted. Interior and exterior paint coatings should be evaluated for cracking, peeling or separation. Areas of entrapped standing water that represent points of high corrosion potential or freezing at altitude should be noted. All areas exposed to high temperatures (e.g, engine compartment, hot air bleed lines for the environmental control system, auxiliary power unit exhaust area, etc.) should be monitored. Security of any insulation blankets or protective trim panels attached by bonding or tape should be evaluated, especially where exposed to leaking hydraulic fluid, oil, coolant, etc. Signs of leaking lubricants, hydraulic fluid, oil, fuel or moisture should be noted as early indicators of potential corrosion sites. Following testing, a corrosion control team composed of representatives from the airframe manufacturer, and military agencies should inspect the airframe for signs of corrosion.

3.3.7 Armament System

The overall objective of armament system testing is to evaluate its performance and supportability. The weapon system power and communication system should be evaluated for proper electrical signals and to determine if any stray voltages are induced due to climatic extremes. During this evaluation, the system should be loaded in accordance with current technical orders and all required system checks accomplished, including a safe-state test. Of course, all weapons will be inert. However, prior to takeoff, the offensive system operator should turn weapon power on and determine weapon status. During cruise, the operator should verify weapon status and options. During final approach to the target, the pilot/operator should unlock the ejector racks and arm the weapons. After egress from the target, the pilot/operator should safe the weapons and lock the ejector racks.

Functioning of the rotary launcher should be evaluated in a worst case asymmetric loading configuration. Modified electronic explosive devices with fuses should be installed at each position in place of actual ejector cartridges. This will permit determination of release signal function without actually releasing stores. During test missions, the operator should exercise all possible combinations of weapon bay doors and launcher positions.

Tests should be accomplished to evaluate the overall adequacy of support equipment during weapon upload, download, and system checkout operations. These tests can be used to determine whether adequate room exists for load crews to manually install weapon umbilicals. Accessibility and maintainability of weapon delivery system line replaceable units (black boxes) should also be evaluated.

If a gun is part of the armament system, its compatibility with the air vehicle and associated subsystems should be evaluated. Compliance with performance and design requirements should be evaluated while firing target practice, armor-piercing, incendiary tracer, and high explosive incendiary ammunition. The ability of the hydraulic power supply to satisfactorily accelerate and operate the gun within specification limits at both low and high firing rates should be evaluated. An evaluation should also be made of the gun clearing sequence. In addition to the items evaluated at normal ambient temperatures, the adequacy of the following items should be evaluated at extreme ambient conditions:

a. Doors provided for safing, loading and other maintenance functions.

b. Design for removal and installation of the gun system.

c. Boresighting procedures.

d. Ammunition loading support equipment, especially the lubricants.

e. Compartment drainage.

f. Gun firing with accumulated ice.

3.3.8 Offensive and Defensive Avionics Systems

The overall objective of this evaluation is to evaluate system performance and operational time lines. Subsystems evaluated would include the avionics computer complex, offensive and defensive radar, inertial navigation system, avionics controls and displays, and command and communication controls.

The offensive radar system should be evaluated to determine its capability to go to "ready" status within the specified warmup time, and the capability of the antenna to rotate throughout its envelope without binding and to transmit on all channels. The reliability and lighting of the avionics controls and displays should also be evaluated. As with all controls, ease of operation should be checked with the operator wearing flight gloves. The radar should be evaluated for degradation in weather, the ability to detect weather, and the effect of ice on the radome.

During all normal preflight communications, the intercom at each crew position should be checked and monitored for interference or abnormal operation. Using mobile radios, transmission on several different test frequencies using preset and manual frequencies should be accomplished. Bandwidth extremes (if possible) and all antenna positions should be attempted. An identification friend or foe interrogator should be used to trigger normal, low modes, and emergency code positions using all antenna positions. If support equipment is available, an interrogation of the transponder beacon should be attempted.

The inertial navigation system should be evaluated to determine its ability to meet ground precision and stored heading alignment time lines and to determine whether navigation accuracy parameters are degraded. Alignment performance and time lines at environmental extremes should be compared with the baseline ground precision and stored heading alignments followed by an hour and one-half of free inertial navigation drift runs. The actual alignment time lines should be compared to specified time lines and those obtained during baseline testing.

The operator should use technical order checklist procedures for avionics system startup, power-off the inertial navigation system after avionic control unit load is complete, input initial data, initiate a precision ground alignment, and record times when each sequence of the alignment starts and ends. Alignment quality estimates, velocities in all three axes, wander angles, gyro and accelerometer bias should be recorded prior to and after platform slew. After the alignment is complete, the system should be placed in the navigate mode and position, and heading velocities and wander angle recorded at 15-minute intervals until 90 minutes have elapsed. All data should be recorded at this time and after accomplishing an overfly position update.

The avionics computer complex should be evaluated to determine its capability to perform within specified limits and operated to determine normal and operational time lines. Comments made by the operator on system performance and faults indicated by self-test should be used for evaluation. The system should be powered up after engine start using normal procedures. During an alert, the system should be powered up after an auxiliary power unit start and monitored for abnormal operation.

The performance of the radio frequency surveillance/electronic countermeasures should be monitored during all tests for proper function and to determine whether the system will transmit and receive properly. Flare and chaff ejector systems should be evaluated for proper operation. Additional information on testing of offensive and defensive avionics systems can be found in Ref 8 .

3.3.9 Central Integrated Test System

The overall objective of these tests is to determine if the system meets contract requirements, to identify deficiencies, and to measure the capability of the system to display properly. This type of system provides onboard self-test of subsystems through passive monitoring and ground readiness tests. The evaluation process would include monitoring and use of the control and display panel and analyzing data recorded on the airborne printer tape and maintenance recorder. The ability of the central integrated test system to monitor and respond to known errors and to load its operational software program should also be evaluated.

3.3.10 Flight Control System

The primary and secondary flight control systems should be evaluated prior to flight for adequate surface rates and authority using normal and alert test procedures. Control sweeps should be performed at both idle and military power. Control movements should be as rapid as possible. The operator should pause 5 seconds at each control position or until full deflection is obtained. These control sweeps should be repeated until the maximum achievable rates are reached. If applicable, the wing sweep system should be evaluated and the flaps and slats monitored for proper operation. Flight control surface authority and control forces should be measured with the control sticks connected and disconnected. Using a hand-held force gage, with the control connected, the force required to move the pilot's control stick at three positions between neutral and full deflection should be measured to establish a gradient. Measurements should be taken in the forward, aft, left and right directions and for left and right pedal deflections. With the control stick interconnect disconnected, the control stick force measurements on both the pilot and copilot sticks should be repeated. A calibrated hand-held force gage capable of measurements in tension and compression is required. Force readings should be plotted against the control position to establish control system breakout, friction, and force gradient values for comparison with specified and baseline values.

The Automatic Flight Control System should be evaluated during flight. Test points should include terrain following and autopilot inputs. Autothrottle tests and automatic flight control system tests involving aircraft attitude changes should also be performed.

3.3.11 Human Factors

Human factors testing during extreme environmental conditions is as important as the testing and functioning of the machine. Hence, it is vital that the test crew function as a genuine team, and that everyone in that team is trained and realizes what the exercise is all about. There must be mutual confidence not only among all the members of the team but also confidence in the test team leader and project engineer(s) to those back at home base and at Command level (Ref 1). The overall objective of human factors testing is to examine system effectiveness while the human operator makes inputs. In addition, it should be determined whether the flight and maintenance crews are provided adequate clothing to function under extreme environmental conditions. Maintenance activities including aircraft servicing, inspection, and the removal and replacement of selected components should be evaluated. Evaluation of unscheduled maintenance tasks on a noninterference basis may also be performed at the discretion of the human factors engineer. Operations including aircraft ingress and egress, normal procedures, preconditioning procedures, alert scramble procedures, and emergency procedures should be evaluated. These evaluations should consider such areas as cockpit environment, workload, and aircrew clothing. Activities and data should be recorded by video tape, monitoring of cockpit environmental parameters, and completion of questionnaires. Another objective of the human factors evaluation is to determine to what extent the aircrew is supported and can effectively operate the weapon systems. This evaluation should primarily be conducted in conjunction with the other system tests.

The test conductor should encourage and accept verbal inputs from everyone on the test team. At the outset, mechanics, avionics and armament specialists, aircrew and all team members should be encouraged to pass on any information on deficiencies, workaround techniques, etc., that need to be included in test reports.

Emphasis should be directed toward how effectively maintenance personnel perform tasks. In addition, it will be determined if the weapon system design provides for personnel to utilize their unique skills and not force undue strain on their capabilities. Tasks should be evaluated with regard to:

a. Safety provisions, especially in water and ice conditions.

b. Capability of protective clothing (e.g., restricting manual and visual access, providing the body with adequate warmth or cooling, etc.).

c. Suitability of support equipment.

d. Impact of cold conditions on servicing, primarily higher viscosity oil and hydraulic fluids and hazard of spillage on skin.

e. Time taken to complete tasks.

3.3.12 Environmental Protection and Anti-Icing Systems

The general objective of this test is to evaluate the environmental protection systems during operations in adverse weather conditions (icing and rain). A secondary objective would be to evaluate the effects of ice accumulations on unprotected components such as landing gear, and radar and communications antennae.

In the Climatic Laboratory, the icing tests should be conducted in two supercooled fog icing conditions and if appropriate in an engine inlet vortex-induced icing condition. The first supercooled fog icing condition should be at an ambient temperature of 0 degrees F (-18 degrees C) with an icing cloud liquid water content of 0.3 grams per cubic meter. The second fog condition should be at 20 degrees F (-7 degrees C) with a cloud liquid water content of 0.5 grams per cubic meter. The engine inlet vortex-induced icing condition should be performed at an ambient temperature of approximately [illegible] degrees F (-3 degrees C) with a puddle water temperature between 33 and 37 degrees F ([illegible] and 3 degrees C)

The icing cloud for the supercooled fog icing test should be produced with icing spray frames located in front of the area to be iced. The icing cloud is then driven with portable fans from the spray frames to the test area. The wind velocity is varied depending on which area is being tested. When icing the windshields and landing gear the wind velocity should be 30 to 50 miles per hour (26 to 43 knots) to simulate ground taxi in wind conditions. The engine and inlet tests should be performed with a low wind velocity, just sufficient to carry the cloud to the nacelle.

In the Climatic Laboratory, the engine inlet vortex-induced icing tests should be performed by placing a concrete "puddle" under the nacelle. This puddle provides water as much as one-half inch (1.3 centimeters) deep and is textured to simulate typical aircraft parking areas. The puddle should be at a distance below the nacelle

which will simulate normal engine inlet height above the ramp for a heavy gross weight condition. The temperature of the water in the puddle should be controlled to the desired temperature by using a water chiller.

The icing cloud characteristics should be measured using a laser interferometer. This instrument will measure cloud liquid water content and water droplet mean volumetric diameter. The interferometer is connected to a computer to store and display measurements. This data will be used to ensure correct test conditions and to document icing conditions.

Ice protection systems to be evaluated include windshield normal and alternate anti-ice, rain removal, landing gear, engine anti-ice provisions including the inlet and front frame, and wings and empennage as appropriate. It should be noted that testing of ice protection systems in the Climatic Laboratory are to be considered preliminary to and not a substitute for in-flight icing evaluations under artificial (icing tanker) and natural conditions.

3.3.13 Support Equipment

Support equipment should be tested in conjunction with air vehicle tests. Testing will consist mainly of functional and interface compatibility checks at extreme climatic conditions. The support equipment will be tested during operation in accordance with technical orders to support preflight and postflight servicing of systems.

Based on previous experience with support equipment in a variety of environmental conditions, primary emphasis should be placed on support equipment operation and function at extremely high and low temperatures. Prior to cold weather testing the support equipment should be winterized in accordance with technical order procedures.

The objective of this testing is to evaluate the adequacy of the support equipment to support ground operations in extreme climatic conditions as well as the adequacy of support equipment operation and maintenance activities. This includes the evaluation of wheeled equipment for maneuverability.

3.4 Safety Planning

Safety is always a prime consideration in planning and conducting tests. Every project manager, project engineer, and team member must take an active interest in safety. The secret to accident prevention is anticipating personnel mistakes, equipment malfunctions, and environmental aberrations which change potential hazards to probable causes of accidents. Safety planning starts with test system design and development and continues through test planning and active testing. Air Force Flight Test Center Regulation (AFFTCR) 127-3 Ref 9, establishes the requirement for application of system safety principles to test project accomplishment. These principles have been extremely effective for climatic evaluations conducted by the Air Force Flight Test Center. Compliance ensures that all tests are conducted as safely as possible consistent with mission objective accomplishment.

Working around as well as operating a flight vehicle in extreme climatic conditions compounds hazards and demands constant attention to safety. Like flight itself, extreme or adverse environmental conditions are unforgiving of the ill-prepared, the complacent, and the uninformed. The added risk/hazard factors, due to these environments, must be stressed to all test team members to stimulate increased vigilance for safety in every aspect of their work. Although extreme cold presents more concerns; extreme heat, wind, or precipitation in any form have their own unique perils. Alone or in combination, they aggravate the efforts to prepare, launch, fly, and recover an air vehicle. In short, safety must be intensified as climatic conditions become more extreme.

3.4.1 Operating Hazard Analysis

Project managers should develop an Operating Hazard Analysis which identifies hazards generated by each test and ensures that adequate precautions aretaken to eliminate or minimize these hazards to an acceptable level of risk. Some hazards relating to tests in extreme climatic conditions are: frostbite, engine inlet icing, slipping on ice, poor visibility, burned skin, fatigue, and reduced personnel mobility (because of cold weather gear).

During this process, project personnel should contact managers of test facilities programmed for use, review documents developed for similar tests, and discuss with other personnel their experiences in similar testing to assist in potential hazard identification and risk reducing procedures.

3.4.2 Test Project Safety Review

Copies of the hazard analysis are distributed to persons from various test disciplines who have been selected to sit on the Safety Review Board. The board members are normally supervisory people selected from organizations having project familiarity, but without direct project involvement, which might present a personal conflict of interest. During the meeting, designated project personnel present test

objectives and methods. Other project personnel and air vehicle manufacturer personnel should be available to answer technical questions which arise. The chairperson should record a summary of the review activity which includes: date, location, attendance, accident accountability or safety responsibility, general risk minimizing considerations, test procedures, test objectives, and the risk levels assigned by the board. Approval of this document normally provides authority to conduct the tests.

3.4.3 Categorizing Hazards and Risk Levels

Qualitative measures of hazards in safety analysis are:

a. Category I - Catastrophic. May cause death or system loss.

b. Category II - Critical. May cause severe injury, severe occupational illness, or major system damage; or require action to prevent a Category I hazard.

c. Category III - Marginal. May cause minor injury, minor occupational illness, or minor system damage; or require action to prevent a Category II hazard.

d. Category IV - Negligible. Will not result in injury, occupational illness or system damage.

A risk level chart is presented in Figure 3. A qualitative classification of possible loss in terms of hazard severity and probability (Risk Level) is as follows:

a. Hazardous. Tests with Category I or II hazards with high probability of occurrence. These tests or activities present significant risk to personnel, equipment, or property, even after all precautionary measures have been taken. Close supervision is required at all times.

b. Medium Risk. Tests with Category I or II hazards with medium or Category III hazards with a high probability of occurrence. These tests or activities present greater risk to personnel, equipment, or property than normal operations, and require more than routine supervision.

c. Low Risk. Tests with Category I or II hazards with low, or Category III hazards with medium probability of occurrence, or only Category IV hazards. These tests or activities present no greater risk than normal operations. Routine supervision is appropriate.

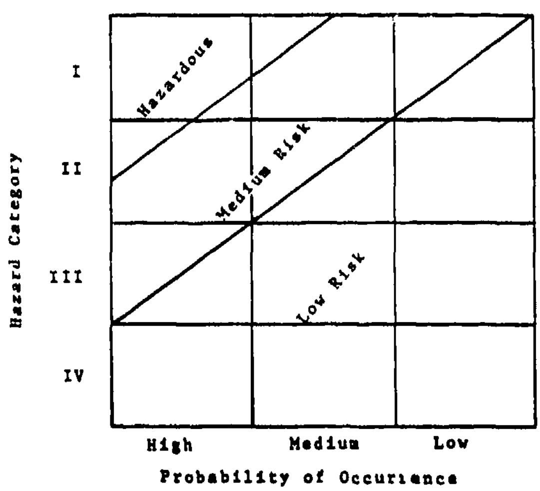


Figure 3 Risk Level Chart

4. CLIMATIC LABORATORIES

4.1 United Kingdom Environmental Facility (12)

United Kingdom engineers at the Aeroplane and Armament Experimental Establishment at Boscomb Down, UK, have taken a very innovative and cost effective approach to construction of an environmental facility in which to conduct thermally-controlled tests. The test facility was developed using a conventional hangar to provide a wide range of simulated climatic conditions from arctic extremes of -40 degrees F (-40 degrees C) and lower, to tropic conditions of 95 degrees F (35 degrees C) and 100 percent humidity and desert-like temperatures of 120 degree F (49 degrees C) and higher.

To simulate arctic extremes a special insulated test chamber is constructed inside the hangar, up to 60.7 feet (18.5 meters) long by 52.5 feet (16 meters) wide by 14.8 feet (4.5 meters) high. Refrigeration is provided by spraying liquid nitrogen at -385 degrees F (-232 degrees C) into air drawn from the chamber which is then recirculated to cool the test subject. Stabilized temperatures of -40 degrees F (-40 degrees C) can be maintained for long periods, and exposure to -76 degrees F (-60 degrees C) can be readily simulated. Personnel working in the chamber must wear arctic clothing and carry oxygen equipment, because of the additional nitrogen in the atmosphere. Air vehicle electrical and hydraulic systems can be checked using ground test rigs and cold air can be supplied to run auxiliary power units and internal combustion engines with the exhaust ducted outside.

For high temperatures and humidity environments, the full test area of 98 feet (30 meters) long by 98 feet (30 meters) wide by 18 feet (5.5 meters) high is available. The air is circulated by heater blowers with a combined output of 4.1 x 10^6 British Thermal Units per hour capable of raising the temperature to 167 degrees F (75 degrees C) and maintaining the desired level within ±3 degrees F (± 1 degree C) for long periods. The water content of the air can be increased up to 0.077 pounds of water per pound of air (kilograms of water per kilogram of air) by injecting steam. One hundred percent relative humidity at 93 degrees F (34 degrees C) and saturated conditions can be achieved and controlled.

The heating effect of solar radiation can be simulated using electric lamps, giving 1120 watts/meter^2 for surface areas up to 33 square feet (3 square meters). The kinetic heating of air vehicle surfaces can be simulated using electric heater mats, with maximum surface temperature of 212 degrees F (100 degrees C).

An ancillary plant supplies conditioned air up to 132 pounds (60 kilograms) per minute at 36 to 122 degees F (2 to 50 degrees C), to simulate air vehicle air conditioning systems or ram-air intakes. There arespecial provisions for the extraction of exhaust gases from the hangar. Thus,air vehicle engines can run while maintaining the test environment, providing the air consumption rate of the engineis less than 110 pounds (50 kilograms) per second mass flow at 122 degrees F (50 degrees C). Admittedly, the ambient conditions immediately start to change but considerable worthwhile data can be obtained before the temperature of the test vehiclechanges significantly.

Use of this environmental facility can save time and cost by highlighting obvious design deficiencies and manufacturing faults before trials in actual environments begin. Also, when the trials take place, comparison with the environmental facility results will give added confidence in the test results. The following are the primary uses for the environmental facility:

a. Demonstrate that the installed instrumentation can be operated, within required accuracy, at the lowest temperature likely to be encountered during the trial.

b. Give a measure of confidence that the air vehicle can operate at the required temperatures. If small enough, the whole vehicle can be tested in this hangar; if a larger air vehicle, parts of it like the nose section, can be examined. The test method is to reduce the temperature in the environmental facility in stages of 50, -5, and -30 degrees F (10, -20, and -34 degrees C), holding the temperatures at each stage long enough to cold soak the air vehicle. At these stages the vehicle can be jacked clear of the ground and with hydraulic, electrical and instrumentation power applied, standard functional checks of all systems can be carried out. In addition, emergency systems such as fuel jettison, landing gear emergency extension, etc., can be checked. With the test vehicle not on jacks, engine starting can be proved, although ambient temperature air must be directed in from outside of the hangar.

c. Prove that standard and special support equipment can operate at the ambient temperatures likely to be met during the trial. It is particularly important to operate cabin heating equipment during a simulated cold test during which relevant parameters such as engine speed, freon pressures and air delivery flow rate and temperature are noted. Thus the exact heat input into the fuselage during the trial is known and operating instructions can be confidently given to the operators. Special ground equipment is an important aspect of air vehicle clearance and defect investigation procedures. If required to be used with the air vehicle, it should be designed to air vehicle standards.

d. Allow the pilot or aircrew to familiarize themselves with quick exit procedures in the case of an emergency at low temperatures, and to highlight problem areas such as sticking canopies and jamming of emergency exits and doors (Ref 10).

4.2 McKinley Climatic Laboratory (3)

The primary mission of the McKinley Climatic Laboratory is to simulate global environmental testing conditions in order that the users may prove and test weapon systems. To accomplish this mission, assigned personnel provide the following services:

a. Operate and maintain all testing facilities to provide environments for testing under approved programs.

b. Provide consultant engineering services for users of the facilities.

c. Design, manufacture and install test support equipment, (e.g., projectile trap for gun firing, ducting for engine runs, etc.), instrumentation, and data acquisition systems.

4.2.1 Climatic Laboratory Description

The main chamber is an insulated hangar with dimensions as follows: 252 feet (77 meters) wide, 201 feet (61 meters) long, 70 feet (21 meters) high in the center and 35 feet (11 meters) high at the sides. An appendant floor area 60 by 85 feet (18 by 26 meters) with a ceiling height of 75 feet (23 meters) was added to accommodate the tail of the C-5 cargo aircraft. Usable floor space is 55,000 square feet (5110 square meters). The size of the chamber permits testing of very large items of equipment and complete weapon systems. Several tests can be conducted concurrently depending on the size and complexity of the individual test items. A series of tiedown points is installed in the concrete floor for anchoring test vehicles and other equipment. Front and plan views of the main chamber are presented in Figure 4.

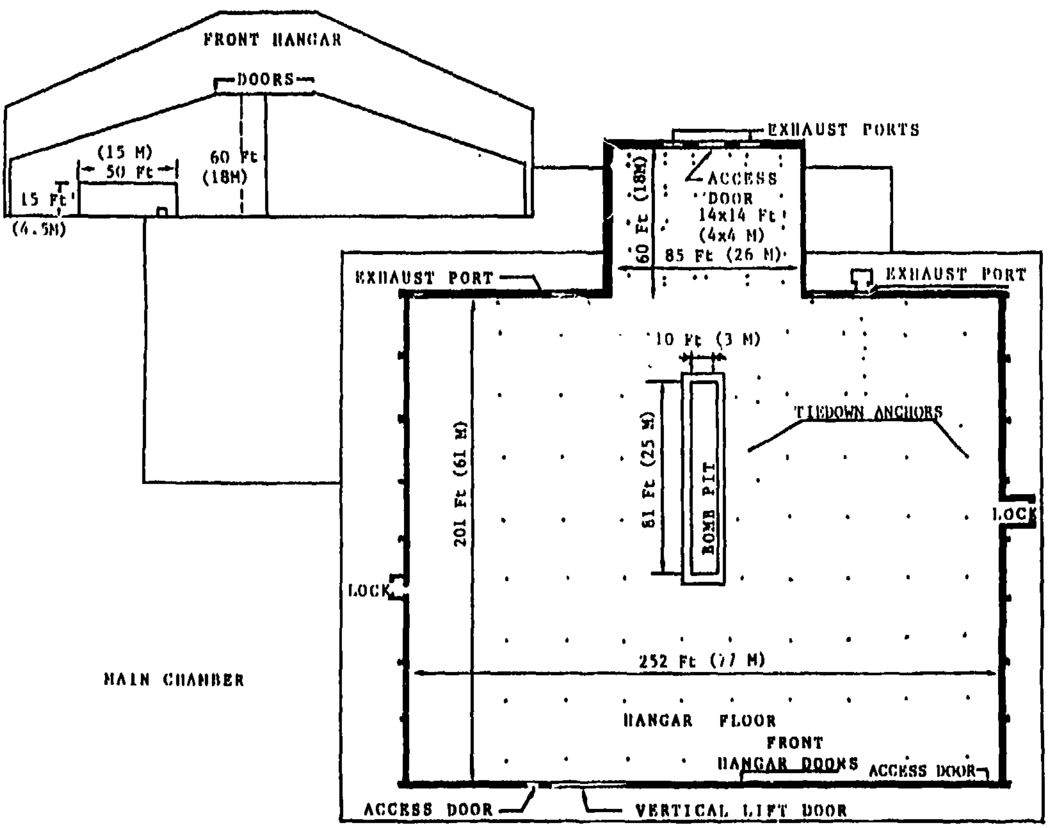


Figure 4. Plan View of Climatic Laboratory Main Chamber

Access to the main laboratory chamber is gained through one of many doors. The main doors, mounted on railroad wheels and flush tracks, are 250 feet (76 meters) wide, 60 feet (18 meters) high (maximum), and can be opened in eight minutes at a Laboratory ambient temperature of -65 degrees F (-54 degrees C). The vertical lift doors (mounted within the main doors) are 50 feet (15 meters) wide and 15 feet (4.6 meters) high, and are used for emergency access to the main chamber or when the main doors are not required. Access can also be gained through a 10-foot (3-meter) by 10-foot (3-meter) door in the south wall and a 14-foot (4.3-meter) by 10-foot (3-meter) door in the east wall of the appendant area. Eight personnel doors approximately 3 feet (0.9 meters) by 7 feet (2.1 meters) exist around the perimeter of the main chamber.

4.2.2 Climatic Laboratory Capabilities

Conditioned air, consumed by operating engines, can be replaced up to a maximum of 650 pounds (295 kilograms) mass per second at ambient temperatures of -65 to 165 degrees F (-54 to 74 degrees C). This air makeup capability is limited to relatively short duration at extremely cold temperatures.

The ambient temperature range capability is from 165 to -70 degrees F (74 to -57 degrees C). Maximum cooling rate of the main chamber is from 60 to -65 degrees F (16 to -54 degrees C) in 24 hours. Relative humidity can be varied from 10 to 98 percent at ambient temperatures of 30 to 160 degrees F (-1 to 71 degrees C), respectively. A schematic of relative humidity limits is presented in Figure 5.

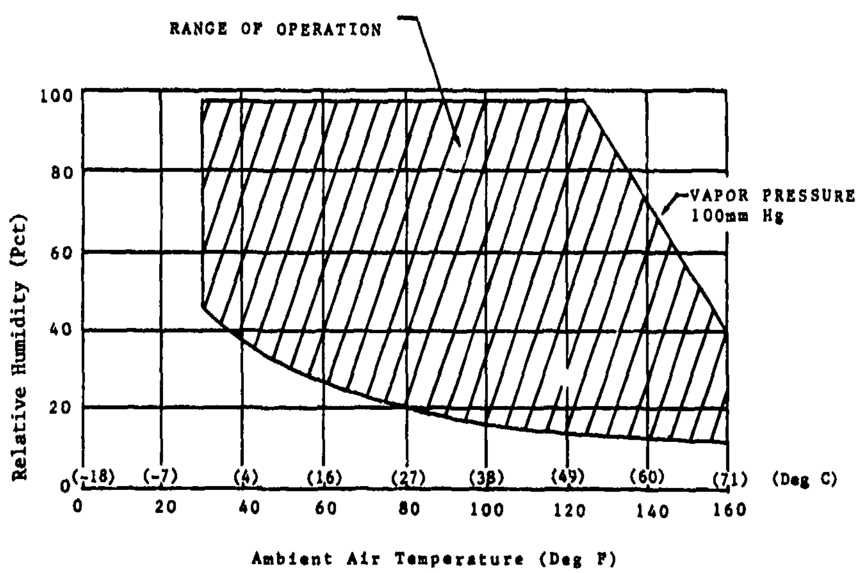


Figure 5 Relative Humidity vs Ambient Air Temperature for Climatic Laboratory Main Chamber

The following electrical power is available:

a. 400 Vac, 3-phase, 60 Hz, 300 amps

b. 208 Vac, 3-phase, 4-wire, 60 Hz, 100 amps

c. 120 Vac, single-phase, 60 Hz, 50 amps

d. 28 Vdc, 356 amps

e. 120/208 Vac, 3-phase, 4-wire, 400 Hz, 25 kw

f. Two portable power carts, 120/208 Vac, rated at 100 kva

Overhead spray frames are provided for creating freezing rain conditions. Icing tests of engine inlets and other test items are accomplished by means of portable icing equipment tailored to individual requirements. Rain, from a light mist to 15 inches (38 centimeters) per hour, can be produced by overhead spray systems to cover areas ranging up to 2,000 square feet (186 square meters).

Solar arrays can be constructed to radiate on all, or part, of a test vehicle and equipment to MIL-STD-210 (Ref 4), requirements. Since heat is the primary concern during high temperature tests, infrared bulbs are installed in the arrays rather than ultraviolet bulbs to reduce cost.

4.2.3 Climatic Laboratory Facilities

A 600-gallon (2270-liter) fuel tank is maintained inside the laboratory for refueling with fuel stabilized at the ambient test temperature. This helps to avoid additional soak time which would otherwise be required to thermally stabilize warm fuel from a refueling truck to chamber ambient temperature when putting it directly into the fuel tanks of the items under test.

A projectile trap, built by Climatic Laboratory personnel, permits automatic gunfiring of weapons up to 40 millimeters inside the Laboratory. Requests for weapon firing support are evaluated for safety based upon rate of fire, velocity, caliber, and length of burst.

Due to the variety and nature of the equipment tested in the Laboratory, considerable attention has been given to providing fire fighting equipment to meet any situation. Both electrically operated and manually controlled systems and a choice of extinguishing materials are available. Portable extinguishers are located throughout the Laboratory.

An overhead water deluge system can deliver 600,000 gallons (2.3×10^6 liters) of water per hour to the main chamber, the main chamber attic, and to the various test rooms, at all ambient temperatures. The attic system is automatically actuated by fusible sprinkler heads. The systems in the other rooms are electrically controlled dry systems with open sprinkler heads. To provide water for the deluge systems, a closed concrete reservoir provides a one-hour supply (600,000 gallons) (2.3×10^6 liters) to the system when all sprinkler heads are flowing. Water is gravity fed from this reservoir to four 2500-gallon (9500-liter) per minute and two 500-gallon (1900-liter) per minute dual-drive pumps. These pumps are normally operated by 120- and 60-horsepower (8950- and 4475-kilowatt) electric motors, respectively. In case of electrical failure, the pumps are operated by automatic starting, reciprocating gasoline engines.

A handline operated water-fog system exists of sufficient size to cover the entire area of the main chamber and the engine and equipment test facility. Each line is equipped with a 10-foot (3-meter) applicator. The nozzles can also be adjusted to a full water stream.

Foam is supplied to the main chamber and the engine and equipment test facility for handline distribution. Dual-drive pumps, capable of being driven electrically or by a gasoline engine, assure coverage under all conditions.

Carbon dioxide handlines provide complete coverage of the main chamber and the equipment test facility. In addition, four carbon dioxide spray nozzles are located on one wall of the engine and equipment test facility. Discharge from these nozzles is accomplished from a control room. These carbon dioxide systems are supplied from a 15,000-pound (6800-kilogram) capacity centrally located storage tank.

There are two unique communications systems in the Laboratory for test purposes: (1) interphone and (2) an intercommunications system. The interphone system is internal to the Laboratory and allows communications between key areas and offices. This system also has paging capability for making periodic announcements and locating personnel. The intercommunication system links the test vehicle, test control booths, and other key areas of the Laboratory and is used for test operations. Audio recordings of tests are usually made on this system.

Several shops located within the Laboratory are primarily devoted to facility operation and maintenance. Test project support can be obtained from these shops.

There are a number of small test chambers at the Climatic Laboratory which are available for test purposes. For a description of these refer to the McKinley Climatic Laboratory Facilities handbook (Ref 11). Information on major items of interest, policies, regulations and procedures can be obtained from the Climatic Laboratory User Brochure (Ref 12). More detailed information on Climatic Laboratory tests, requests for use, safety information and test phases is contained in Section 8.1 of the Appendix.

5. CLIMATIC DEPLOYMENTS

Subsequent to the Climatic Laboratory tests and after safety of flight problems discovered in the Laboratory are repaired and necessary changes incorporated, the test vehicle should be deployed to test sites for continuation of all-weather testing. The particular test site, arctic, desert, tropic or adverse-weather, depends on the test vehicle requirements and the season of the year. There is normally a short window during each season when the probability of experiencing the most extreme conditions is highest. Typical windows for maximum exposure to climatic extremes in a given area of the northern hemisphere are shown in Figure 1.

During each test phase, the test vehicle will be operated as closely as possible to an operational scenario while accomplishing the objectives stated in the test plan. The vehicle will be operated and maintained in accordance with technical orders, while being exposed around the clock to the most extreme ambient conditions available.

As opposed to the Climatic Laboratory, the instrumentation system used during a deployment must be flight worthy. External power enables powering the instrumentation system prior to engine start. If air-conditioning is required for the instrumentation system, particular attention must be exercised so as not to affect air vehicle systems in proximity.

Long-range weather forecasts are available from weather specialists. These forecasters have the expertise, especially with the weather satellite system, to predict overall weather conditions (e.g., jet streams, high and low pressure cells, prevailing winds, precipitation, etc.). What they cannot do very well is predict the conditions on the earth's surface in a particular area because of local phenomenon such as a temperature inversion. The most accurate local weather predictions are best obtained from a local weather forecaster with several seasons experience.

The extremes of temperature at a given site will not occur at the same time every season and indeed will not occur every year. Therefore, if a commitment is made to deploy to a given site, the test team should glean as much test information as possible. Even milder extreme weather can be made useful by conducting adverse weather evaluations.

Typical problems encountered during both flight testing and operations in the field are listed throughout section 5. These problems show the types of anomalies that can be encountered in a given extreme condition. Some of these problems were determined from quantitative data obtained during flight test, and others were obtained from discussions with operations and maintenance personnel during the author's fact finding trips to locations where military units operate or test in extreme climatic conditions. The qualitative information, while perhaps not as objective as test data, is considered equally as valid because its origin was from problems encountered in the field by professionals during the conduct of their mission.

Operating Instructions should be developed and updated regularly for use during maintenance and operations in extreme climatic conditions. Personnel should be briefed prior to functioning in climatic extremes. (1)

It has been the author's experience during testing, and this has been verified by essentially all interviewees during fact finding, that weapon system support equipment is, in general, a weakness for all concerned. The major problems are lack of proper qualification testing, lack of emphasis on testing and repair of known deficiencies, and lack of quality conditioning kits and proper technical orders.

5.1 Test Arrangements, Logistics, and Host Base Support

Off-site tests at extreme climatic conditions typically require long range planning to establish test requirements. As soon as the requirements for testing are established, the host base should be formally contacted to determine the availability of support equipment and materials and which of them must be supplied by the user. The initial contact should be made a year or more in advance of the test. Substantial lead time is often necessary for the host base to integrate the test support with their normal workload. This first contact by correspondence can be in the form of a Program Introduction document, or a letter requesting facility use and support. More details can be provided in a Memorandum of Agreement or a contract with essentially the same information. When the host base assigns a point of contact, periodic telephone calls with that individual should prove valuable to clarify or update requirements.

The project manager should arrange for a site survey at the host base a minimum of six months prior to occupation of facilities. Special requirements may take that long to provide, especially if any construction or rewiring is required. A small team of people, consisting of the project manager, project pilot, project engineer, maintenance chief, and logistics plans representative, should attend the site survey for a face-to-face meeting with site personnel to discuss the contents of the Program Introduction document item by item. The latest Program Introduction document should be forwarded to the host base at least one month in advance of this meeting. In particular, a detailed list of support equipment should be included. During negotiations at this meeting, the project manager should provide the host base with copies of the latest test plans. When a change to an agreed test program becomes

necessary, it must be coordinated with the host base as soon as possible to allow time for modifying scheduled support. Depending on test complexity and scope, more than one face-to-face meeting may be required to finalize the support agreement. A summary of topics to be addressed is included in Table 1.

Table 1

Items to be Addressed When Requesting Support

I. Program and Mission Information
1. Test System Description
2. Schedule
3. Instrumentation
4. Test Procedures
5. Test Envelope

II. Operational Requirements
1. Operational Hazards
2. Command and Control
3. Communications
4. Meteorological Information
5. Hangar Space
6. Runway/Operations Facilities
7. Control Tower
8. Fuel, Oil, Lubrication
9. Maintenance/Shop Space
10. Support Equipment
11. Fire Suppression
12. Exotic Fuels and Propellants
13. Armament/Munitions
14. Life Support
15. Safety Chase
16. Logistics
17. Radio Frequencies
18. Engine Oil/Fluid Samples
19. Engine Trim Pad
20. Ranges

III. Instrumentation and Data Acquisition
1. Calibrations/Project History File
2. Telemetry
3. Encryption
4. Real-Time Displays (Cathode ray tube, Strip chart, etc.)
5. Mission Control Center
6. Photographic (Ground Documentation, Airborne, etc.)
7. Laboratory Requirements
8. Data Processing/Output
9. Power Requirements

IV. Base Facilities
1. Personnel Quarters
2. Office Space/Telephones/Conference Rooms, etc.
3. Transportation
4. Supply, Spares, Storage, etc.
5. Medical
6. Public Affairs
7. Security
8. Mess

An alternate test site should be selected as a backup in the event that primary site weather conditions are not adequate during the proposed test period. The process for establishing alternate host base support is the same as that for the primary site. The decision to go to the alternate site should be based on current weather trends and predictions and made not later than two weeks prior to testing.

Arrangements must be included for outside parking and hangaring the test vehicle for maintenance when required, and setting up special test equipment. Most new programs will require a portable data processor as well as special instrumentation data acquisition equipment which requires temperature controlled, secure areas. The host base should also be informed of any portable weather station or equipment which might require set up in the vicinity of the test vehicle. Finally, arrangements must be made to obtain local weather data at the host base during the test period. This data will be used to supplement the data obtained from a portable weather station.

Many new weapon systems require unique support equipment. New subsystem test sets, high pressure hydraulic carts, and new or unique diagnostic equipment are a few of the items which fall into this category. These items must be arranged for by the requester, and shipped, usually by special assignment airlift, to the test site. Other standard items of ground support equipment (e.g., electrically powered generation units and maintenance platforms), are generally available at the host base.

During negotiations at the host base site survey, the project engineer and logistics representative from the requesting agency should review the support equipment items one by one and decide who will provide them and whether on a dedicated or on-call basis. The maintenance specialist can tour the host maintenance and support equipment facilities following the meeting to resolve specific questions regarding available support equipment. The ranking technician for each system should be responsible to make sure all necessary bench stock, tools, etc., are deployed with their system.

Facilities which are necessary for climatic deployments include storage space for tools, spares and equipment, and office space. Power requirements for both maintenance and instrumentation, desks, chairs and telephones, cooling and heating requirements, etc., should be included in the Program Introduction document and negotiated at the site meeting.

Other host base support which should be addressed involves the housing, feeding and transporting of the test team. Requesters may have to go directly to the local community to obtain housing. Billeting arrangements should include messing facilities. Rental vehicles or other transportation should be arranged for the duration of the test period. A good rule of thumb is three people per midsize vehicle.

5.2 Cold Arctic Tests

The aim of the cold weather trials is to demonstrate the ability of an air vehicle and all its systems, in all its roles, to operate in the extreme cold environments likely to be met by the service operators. Thus the safety, reliability, maintainability, and operational effectiveness need to be examined at low, ground level temperatures and can only be adequately confirmed during a practical trial. The normal approach is to conduct comprehensive low temperature tests, during which critical areas or components are identified, followed by strip examination by the manufacturer of selected components. At the end of the trial, it is necessary to recommend ground level temperatures, precautions and operating limitations which can be respected in a practical situation. Two important points should always be borne in mind. First, the individual component environmental type test conducted during the manufacturer's development work do not give an exact and conclusive representation of actual service conditions. They may, however, show a high degree of confidence that the components will function satisfactorily in the field when assembled into a complete system. Secondly, it should be appreciated that an air vehicle flying at altitude in an ambient air temperature of -75 degrees F (-59 degrees C) is of little clearance value because at the speeds at which modern air vehicles travel, the external surfaces are enveloped in a boundary layer of heated air (with all systems operating in a comfortable environment). However, an aircraft parked in the open and cold soaked to -30 degrees F (-34 degrees C) faces a much more stringent test when it comes to engine start and operations of the air vehicle systems, Ref 10 .

Cold arctic tests in the northern hemisphere should normally be conducted from the first of December to the end of February. Adequate lead time should be scheduled to allow the test team and test vehicle to be established at the deployment site before the first tests to be conducted. An ideal test situation would be for ambient temperature to decrease gradually over a period of time so that a "build-down" in test severity could be achieved. In actuality, this build-down in ambient temperature is seldom achieved. A more common occurrence is relatively constant ambient temperature with some small diurnal variations, that is usually warmer than desired. Extreme patience and willingness to deploy long enough are required to take advantage of the extremely cold ambient temperatures when they come. (4) (6) (10)

The test approach is to cold soak the air vehicle for extended periods at extremely low temperatures then demonstrate response to various design mission requirements (alert, self-suffiency, etc.) using current technical order procedures. In general, cold weather related problems will begin at 0 degrees F (-10 degrees C) and there will be an indication of the most severe problems by the time -20 degrees F (-29 degrees C) is reached. However, at extremely cold temperatures (-40 to -65 degrees F) (-40 to -54 degrees C) failure to start the systems and total system failures are encountered. (4) (6) (10) (12)

The desired ambient temperature for an adequate arctic test is at least -20 degrees F (-29 degrees C). Occasionally ambient temperatures in the arctic or antarctic dip to -55 or -65 degrees F (-48 to -54 degrees C) and remain there for a week or more. The specifications for most air vehicles require operations down to at least -40 degrees F (-40 degrees C) and the ability to withstand -65 degrees F (-54 degrees C), with subsequent operation at -40 degrees F (-40 degrees C). In a truly arctic environment, (i.e., Eielson AFB, Alaska, or Yellow Knife, Alberta, Canada) extremely cold temperatures are accompanied by very little snow or wind. In this case, one aircraft taxiing for takeoff can cause ice fog, reducing visibility to zero for an hour or more. While other areas at north latitudes of 55 to 60 degrees may not experience such extreme ambient temperatures, they may have consistent strong winds and substantial precipitation. These locations experience a completely different set of cold weather problems (e.g., freezing rain, blowing and drifting snow, and wind chill factor). Freezing rain produces extremely heavy, dense ice, which must be removed before flight, and if experienced in flight, can cause low visibility, structural and engine foreign object damage and reduced performance.

Typical problems encountered in a cold arctic environment are listed in Table 2. These problems show that cold arctic tests highlight malfunctions of equipment, usually the simple aspects which have been overlooked in the design stages. These problems include those encountered while flight testing in the cold dry arctic climate and also encompassing those experienced by personnel actually operating under these extremes.

Table 2

Typical Problems Encountered in an Arctic Environment
[(1) (2) (3) (7) (10) (11) (12) (13)] (see note)

1. Hydraulic systems malfunction.
2. Pneudraulic actuator capacity inadequate.
3. Pneudraulic accumulator hand pump capability inadequate.
4. Control valves malfunction.
5. Auxiliary power units, jet fuel starters and support equipment engines difficult to start (external heat required).
6. Aircraft engines difficult to start, and change trim.
7. Primary and secondary flight control surface rates/deflections slow or incomplete.
8. High control forces.
9. Brake release incomplete or time increased.
10. Onboard test monitor systems malfunction.
11. Hydraulic fluid, fuel, engine oil leaks. (Synthetic seals don't last as long as natural rubber seals).
12. Onboard test and monitor systems fail.
13. Avionics systems and computers fail.
14. Air-conditioning systems inadequate, slow to warm crew compartments.
15. Ice from rotor blades cause engine damage.
16. Batteries don't function and need to be removed at -20 degree F (-29 degrees C) and below. Cables fray from frequent removal and replacement.
17. Hydraulic fluid becomes more viscous causing pump cavitation, deteriorated braking and nosewheel steering, sheared drive shafts, and slow landing gear retraction.
18. High idle thrust on slick taxiways and runways cause steering, braking and control problems.
19. Snow and ice difficult to clear from taxiways and runways.
20. Runway condition readings are inconsistent.
21. Landing gear centering cylinder and doors malfunction.
22. Rotor blades delaminate or debond.
23. Low humidity causes increased static electricity and fire hazard.
24. Open hangar doors cause water pipes to freeze. (Circulating water alleviates this problem).
25. Fuel controls and pneumatic drills malfunction due to trapped moisture.
26. Windows crack due to stress concentrations.
27. Slow logistics of spare parts (extra spares should be stocked prior to seasonal extremes).
28. Toilet systems freeze.
29. Gun gas residue cannot be washed from engines.
30. Epoxy and polyester sealants and adhesives won't cure.
31. Changed tolerances due to differential contracting of metals cause malfunctions of landing gear components, and flight control rigging changes.
32. Plastic and metals become brittle, electric wire insulation cracks.
33. Blowing snow collects in open cavities and engine inlets.
34. Support equipment wheels sink in snow.
35. Snow and ice removal from test vehicle is difficult.
36. De-icing fluid causes short circuits and corrosion in microswitches, pitot heaters and electrical connectors.
37. Urea and salt used on slick runways cause material corrosion. Sand causes foreign object damage.
38. Breathing problems caused by engine exhaust fumes.
39. Poor depth perception and sunburned retinas caused by reflection from snow covered areas.
40. Maintenance procedures require more time and more personnel.
41. Clothing too bulky (vapor barrier is a better concept).
42. Slick surfaces on aircraft and ground.
43. Drowsiness, fatigue, colds, and influenza occur more frequently.
44. Nosebleed, dry skin, dehydration caused by low humidity.
45. Psychological depression due to long dark periods. (One commander recommended development of competitiveness between crews to alleviate this problem).

Note: The numbers under the title denote the information source, by visit location, shown in Table 8.

In terms of the most severe problems, (e.g., complete systems breakdown, inability to meet mission requirements, and total human failure) the very cold arctic climate is the most severe extreme environment in which to conduct flight vehicle operations. In general, it is the auxiliary power unit/engine starting, and in the case of helicopters, main rotor gear box lubrication and rotor engagement, which is likely to cause problems. Packing, gaskets, and synthetic rubber parts used in hydraulic and pneumatic systems lose their resilience and fail to return rapidly to their original

form after deflection at extremely low temperatures. Lubricants may thicken and lose effectiveness. Hydraulic systems may experience high pressures, particularly during or shortly after engine start. Leaks in the hydraulic and fuel systems are common until the components/fluids are warm. Flight controls may require several cycles or extended warmup time to function properly. Pneumatic systems may lose their charge, particularly if serviced in a warm hangar, then towed out into the extreme cold. Likewise, "temperature shock" experienced in such a series of events puts great stress on flexible seals. Use of dissimilar metals is also a source of difficulty in cold weather. A steel valve core in an aluminum housing which loses its effective seal at high temperatures may bind at low temperatures. A bronze bushing on a steel shaft which had excessive clearance at high temperature may bind or seize at extremely low temperatures. Closure and sealing strips become hard or brittle and break from shock or vibration. Cold temperatures stiffen metals, often increasing the voltage required to "make or break" an electrical contact. Blowing snow may enter the cockpit or other compartments, melt, and either produce the effects typical of moisture, or freeze and cause binding. Materials, particularly seat covers, inlet plugs, electrical connectors, and insulators become brittle at low temperatures. A great many maintenance problems occur when trying to handle devices while wearing thick gloves. Access holes are often too small, and clearances to perform a task may be inadequate, while wearing a parka and gloves. Both nickel-cadmium and lead-acid batteries lose their efficiency at low temperatures. This may affect auxiliary power unit or engine start procedures. Buttons and warning lights may stick or indicate erratically. Ground handling may require special techniques or equipment. Cockpit heating may be inadequate, or too slow, or both. Most of the difficulties encountered in arctic conditions occur in the time from engine start to about 30 minutes after takeoff, after which most aircraft subsystems have reached operating temperature.

Chill caused by wind creates extreme apparent temperatures, which produce frostbite and require additional body protection. In cold air, even moderate wind will accelerate heat transfer from exposed skin. The principal danger is the formation of local cold spots on the windward side of the body, resulting in excessive heat loss from small areas. When the wind chill factor is high, work can become dangerous when certain rules are not observed. The smallest task can become time consuming and complicated and more people are often required. Heaters should be available to warm personnel and material. Maintenance crews should work in pairs (buddy system) continually watching each other for signs of fatigue and frostbite. Peripheral vision is impaired by the parka hood and people wearing glasses are at a disadvantage because vision may be impaired by lenses freezing over. Temporary shelters should be available to enable essential components of a test vehicle to be replaced quickly to avoid the loss of valuable trials time and results. Work should be arranged in relays of short duration and with continual surveillance. During the planning stage, time should be allowed for acclimatization and the fact that most servicing tasks will take about twice as long to complete as in a temperate climate(Ref 10). Windchill tolerance problems are discussed in detail in Ref 13.

5.3 Hot Desert Tests

Hot desert tests in the northern hemisphere should normally be conducted from mid-June to the end of August. The desired conditions for desert tests are at least 105 degrees F (41 degrees C) with high solar radiation. System specification requirements are usually 120 degrees F (49 degrees C) and 355 British Thermal Units per ft^2 (1119 watts per $meter^2$) per hour solar radiation. The best sites are usually those close to sea level where high solar radiation occurs and ambient temperatures remain high overnight such that total system heat soaking occurs.

The test approach is to heat soak the test vehicle for extended periods of time at the extreme hot temperature and solar radiation, then demonstrate response to various design mission requirements at worst-case conditions. Indications of the most severe hot weather related problems will begin to appear at 105 degrees F (41 degrees C).

High temperature, low absolute and relative humidities, blowing sand and dust, wind and high solar radiation are the primary problem sources during hot weather tests. High temperature affects all types of equipment. The strength of metal parts is decreased. Chemical reactions are often accelerated with increasing temperature. At surface temperatures above 130 degrees F (54 degrees C), packing, gaskets, and other synthetic rubber parts in aircraft pneumatic and hydraulic systems often take on a permanent set. Fuselage compartment seals may deteriorate and permit water intrusion. Synthetic rubber seals may lose plasticizer via vaporization and leaching, thus resulting in binding in a large variety of hydraulic valves and instruments using these seals. Lubricants may break down at high temperatures in gear boxes, actuators, or engine-driven mechanical power takeoff devices. Avionics and all other electrical components are sensitive to high temperatures. Use of dissimilar metals in close contact may prove unsatisfactory due to differential expansion (e.g., a steel valve core in an aluminum housing, a bronze bushing on a steel shaft). Synthetic rubber and plastic tend to discolor, crack, bulge, check or craze. Closure seals may soften and stick to contacting parts. High surface temperatures are often encountered in a closed cockpit exposed to high intensity solar radiation. Consequently, plastic may soften, surfaces may delaminate, and equipment may be too hot to touch. Self-test devices, cathode ray displays, head-up displays, inertial navigation systems andall computer equipment are susceptible to failure.

Typical problems encountered in a hot desert environment are listed in Table 3. These problems also include those obtained quantitatively during flight test and qualitatively by personnel during operations in this type environment.

Table 3

Typical Problems Encountered in a Hot Desert Environment
[(3) (4) (8) (13)] (see note)

1. Auxiliary power unit overtemperature shutdown.
2. Excessive fuel venting due to fuel expansion.
3. Low hydraulic pump pressure.
4. Fuel pump cavitation, fuel line vaporlock, and engine flameout.
5. Avionics equipment bay overtemperature.
6. Support equipment overtemperature and inadequacies.
7. Brake and tire overtemperature.
8. Poor engine performance.
9. Engine compressor-blade and helicopter rotor-blade erosion due to dust.
10. Shoes stick to tar on parking ramp or ship deck.
11. Warm sea water reduces cooling of aircraft carrier engines.
12. Extreme diurnal changes in temperature.
13. Gas expands in systems.
14. Dark painted surfaces absorb heat causing high surface temperatures and peeling paint.
15. Ordnance and chemicals require special attention.
16. Obnoxious flies and poisonous critters abound.

Note: The numbers under the title denote the information source, by visit location, shown in Table 8.

Dust and sand generally affect equipment with bearing surfaces and closely fitted moving parts. In such a location, dust accelerates the breakdown of lubricants into acidic by-products which can corrode metal parts. During periods of high winds, sand or fine dust may penetrate otherwise effective seals. In electrical equipment, dust may get between moving parts of very small switches or relays and cause binding or develop high resistance between contact surfaces. Contact points may stick or eventually burnout. Dust also accumulates between high tension electrodes in radar equipment and promotes arcing. The armatures of motors and generators are rapidly damaged by sand or dust. On equipment with display windows or screens, wiping away of accumulated sand or dust may scratch the surface and impair visibility. Fine dust which accumulates and remains on surfaces is an excellent nucleus for condensation. It absorbs and retains moisture and holds it in close contact with the surface, where, in conjunction with salts, it may form a corrosion cell. (8)

Solar radiation is also a significant factor. The ultraviolet portion of sunlight promotes deterioration of fabrics. Exposure to sunlight may raise the air temperature in a closed cockpit well above 170 degrees F (77 degrees C) through the "greenhouse effect". (8)

Testing in a hot weather environment places heavy demands on the environmental control system for cockpit and electrical equipment cooling. The temperature and volume of cooling air and the distribution of such air to avoid serious temperature stratification are of primary interest during ground and low-level flight operations. It may prove necessary to leave certain pieces of equipment turned off during ground operations or to provide external cooling. Low-level flight operations at high engine power settings may result in excessive temperatures in the hydraulic system or in generators and motors. Ground operations and low-level flight are usually of primary interest in hot weather testing. (8)

Testing and operations in a hot weather environment also place heavy demands on personnel. The body must be completely covered to prevent sunburn and maintained as cool as possible to prevent heatstroke and prostration. Much of the current military gear is not designed for human comfort, (e.g., heavy, dark colored, nonporous) and promotes fatigue and dehydration through perspiration. Chemical warfare suits would be intolerable in an extremely hot climate. It was recommended by one commander that testing be done on military clothing to determine what should be worn in extremely hot climates. (8)

Hot surface temperatures tend to extend maintenance time and increase fatigue, which aggravates physiological and psychological problems. Rest and sleep are difficult, which also increases fatigue. In some cases, maintenance is conducted at night or in the early morning hours. Human tolerance and attention span, and muscle reflexes are reduced, which decrease staying time on the job. Sunglasses are required to reduce the glare from bright surfaces, and dust and wind cause eye contact lens problems. (8) (13)

5.4 Tropic Tests

Tropic tests in the northern hemisphere should normally be conducted from mid-September to mid-November. The requirements for tropic tests are two-fold. The first is to operate air vehicle systems in a high ambient temperature, high humidity

environment. The second requirement is to evaluate corrosion effects of moisture from condensation and rainfall and material deterioration as mildew growth progresses. Corrosion effects are not readily apparent until the test vehicle has been continuously exposed to the tropic environment for at least six weeks. The effects of these conditions is greatly retarded, if they occur at all, when temperature and humidity are reduced, and when experiencing large diurnal ambient temperature cycles.

Normal operational use of the weapon system is a good approach to tropic testing. Emphasis should be placed on environmental control system performance, water intrusion/entrapment, electrical equipment performance, corrosion, freezing of trapped water at altitude, effects of moisture from condensation, mildew growth, avionics equipment cooling, Instrument Flight Rules procedures, wet runway operations, effectiveness of rain removal solutions or pneumatic systems, erosion of windscreens or their protective coatings, and lighting effects during flight through rain. It should be recognized that testing under true tropic conditions is an excellent means for determining corrosion potential. No suitable alternative to the natural environmental tropic sites in the Canal area of Panama has been found.

The best technique for growing fungus is to lay the test article on the ground and cover it with a canvas tarp. This method eliminates airflow while allowing heat and moisture to build under the cover. Typical problems encountered during operations and testing in tropic environments are contained in Table 4. (5) (9)

Table 4

Typical Problems Encountered in a Tropic Environment
[(5) (9)] (see note)

1. Fungus/bacteria growth in oil, hydraulic fluid, and fuel, plugs mesh screens and filters especially if water is entrapped at the bottom.
2. Canopy/windows fog due to condensation.
3. Environmental control system doesn't separate all water, produces fog, condensation runs through avionics racks, electrical short circuits.
4. Aircraft hydroplanes on wet runway.
5. Chemical protective suits too hot.
6. Paint fades, blisters and peels.
7. Metal corrodes.
8. Fire suppressant foam deteriorates in containers.
9. Injuries infect quickly.
10. Water becomes unpalatable quickly.
11. Wood rots quickly.
12. Moisture/galvanic effects cause corrosion in electrical connectors and results in metal pitting.
13. Salt laden air causes corrosion, including internal engine components, if near ocean.
14. Water intrusion, moisture in cockpit, etc.
15. Rain erosion.
16. Lightning associated problems.

Note: The numbers under the title denote the information source, by visit location, shown in Table 8.

High absolute and relative humidities, rain, and relatively high ambient temperatures between 70 to 95 degrees F (21 to 35 degrees C) are characteristic of a tropic environment. Daytime relative humidities greater than 70 percent and nighttime relative humidities of 100 percent are typical. Effects on air vehicle systems are primarily those related to moisture. Flight through rain may result in water intrusion/entrapment in the cockpit area or any number of wing and fuselage compartments, as well as damage by lightning to a variety of systems. High absolute humidities may overload the environmental control system water separator, allowing excessively moist air or even visible moisture to enter the cockpit and air conditioned bays. This, in turn, can severely degrade electrical equipment performance. It can alter the electrical constants of tuned circuits, causing loss in sensitivity. Moisture may be absorbed by resistors, capacitors, and insulating materials. Water entering the cockpit area during ingress/egress in rain can create any number of electrical problems in the cockpit. Trapped water can cause corrosion, or it can freeze at altitude and cause binding of control surfaces, control cables, and throttle cables. Descent from prolonged flight at high altitudes (low ambient temperatures) into hot, humid air may result in fogging of the canopy and windscreen, a condition the DEFOG feature may not be able to correct quickly enough to be acceptable. Flight operations in or near clouds may impair communication equipment. Mildew growth can deteriorate materials in seals, covers and insulators. In electrical equipment, fungus growth can provide electrical bridges and cause arcing or burning, or can breakdown insulating material. The by-products of such growths can contribute to breakdown of lubricants and corrosion of metals (Ref 14).

5.5 Adverse Weather Tests

Adverse weather tests are normally conducted in the late winter or early spring in a climate usually experienced in Canada, northern Europe and the United States. Specific conditions desired for the tests include the following:

a. Ambient temperature in the range of 20 to 40 degrees F(-7 to4degrees C).

b. Frequent exposure to rain, sleet, snow, and freezing rain.

c. Slippery taxiways and runways with a runway condition reading as low as six.

d. Crosswind components up to 20 knots during taxi, takeoff and landing.

e. High surface winds over salt water.

f. Instrument meteorological conditions for in-flight evaluations.

g. Temperature/humidity combinations conducive to airframe/engine icing during ground operations.

These tests should be accomplished under the working philosophy that operational test and evaluation objectives receive the highest priority. Thus, they should be accomplished concurrently with operational missions whenever possible. When it is not practical to satisfy special test objectives during operational profiles, dedicated flights must be conducted.

Freezing rain on test vehicle surfaces, taxiways and runways causing low runway condition readings are principal problem areas during these tests. Removing this ice from air vehicle surfaces using hot ethylene glycol is time consuming and hazardous and can result in arcing electrical contacts and poor visibility through plexiglass surfaces.

Exposure to sand, salt, and urea, used to increase runway condition readings, can create foreign object damage and set up corrosion cells. Some low slung engine inlets can accrete ice if the engines are operated over standing water. A vortex is generated which carries the liquid water into the inlet. The venturi effect in the inlet causes a decrease in temperature and allows ice to accrete on engine front face components. When engine rpm is accelerated, this ice can shed into the engine and cause damage (Ref 15). Typical problems enccuntered in an adverse weather environment are listed in Table 5. (3) (11) (12)

Table 5

Typical Problems Encountered in an Adverse Weather Environment
(3) (11) (12) (see note)

1. Directional control and braking problems on slick surfaces.
2. Ice accumulations on vehicle surfaces.
3. Engine inlet ice accretions during ground operations.
4. Water and blowing snow accumulations in openings.
5. Protective clothing too bulky.
6. Difficult to tow aircraft and support equipment in snow.
7. Hydraulic fluid leaks.
8. Difficult for personnel to stay dry and warm.
9. Water spotting on cockpit displays.
10. Corrosion in landing gear actuators.
11. Corrosion in engine components due to flying through salt moisture.

Note: The numbers under the title denote the information source, by visit location, shown in Table 8.

6. TEST REPORTING

The reporting process is a major undertaking that requires considerable effort and cooperation from all involved. Integration of report planning into test planning and careful execution can save time, avoid distress and minimize revisions. The responsibility of publishing timely reports of high quality falls on the project manager, but he needs enthusiastic managerial support from technical and project supervisors as well as authors. The acquisition management organization is the controlling organization for whom a test program is generated and has overall management responsibility for the item being developed or tested. The basic requirement, scope, types, content, format and security classification of reports should be mutually planned and established by the acquisition management office and the test organization during test planning. Reporting requirements must be established as early as possible to provide guidance to all concerned and allow the author(s) to initiate preparation. It should be noted that a report can be quite large or very small depending on the amount of information to be documented. Reporting procedures and content can be found in AFFTC Supplement 1 to AFSC Regulation 80-20 (Ref 16). A guide to the detailed methods of writing a report can be found in Ref 17 .

6.1 Service Report

Service Reports, or deficiency reports, as they are sometimes called, are action tools for correction of any type deficiency, shortcoming, or proposed enhancement discovered during test and evaluation of a weapon system. One method for accomplishing this reporting is described in Technical Order 00-35D-54, Ref 18). These service reports should be published in the appendix to the final technical report to preserve them for future reference. When these service reports have been approved at the project level, they are forwarded to the acquisition management office for resolution. Usually the management office resolves the deficiency by manufacturer redesign, or by a procedural change.

On large test programs, a computerized system is essential to continually monitor the status of potential deficiencies (watch items) and those which have been determined to be deficiencies. These items frequently number in the thousands, and can consist of anything from the wrong size fastener to a deficient control system or basic airframe flutter. The same computer system can be used to track the effectiveness of corrections.

6.2 Progress Report

These periodic reports are intended primarily to apprise the acquisition management office of test progress or preliminary test results. The frequency and type of progress report required (telephone, message, etc.) should be mutually agreed upon by the responsible test organization and the management office during the test planning phase.

6.3 Preliminary Report of Results

This report contains the overall test and evaluation results and is presented to the acquisition management office within one to two weeks after the final test is conducted. The preliminary report consists of briefing charts and a hard copy which contains narrative supporting the briefing. The presentation is intended as a timely, concise briefing given to decision makers with principal findings and results pertinent to critical management issues. Technical data can be attached as backup material. Content, level of detail, and timing should be mutually agreed upon by the acquisition management office and the responsible test organization. This report is published, but does not take the place of the technical report.

6.4 Technical Report

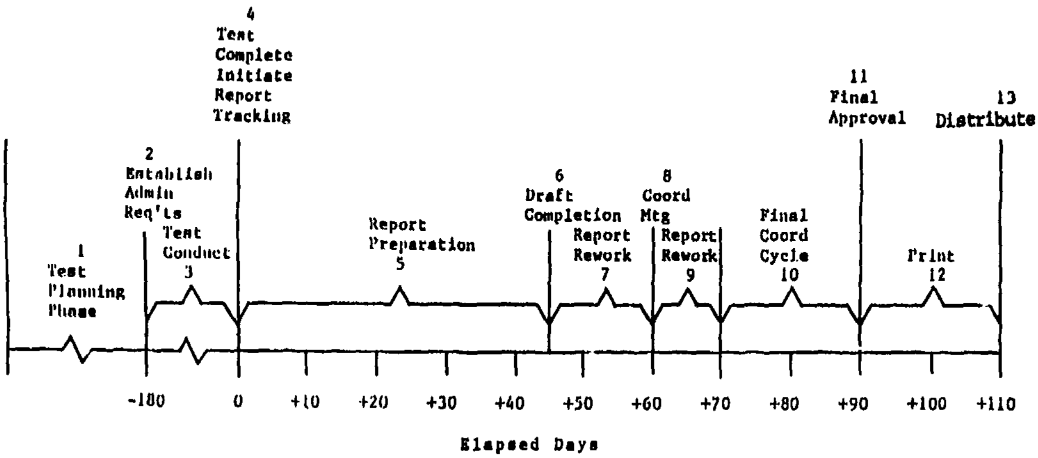
The technical report is intended as a final, historical report of the entire test program effort, which presents test and evaluation results, and is <u>not</u> normally considered an action document. It does include conclusions and recommendations, but the service reports are the action documents. It is basically the final product of a test program, and should get considerable attention from all levels of management. The Air Force Flight Test Center uses the Author's Guide (Ref 17), for development of technical reports.

6.4.1 Report Schedule

In order for the information to be available to operational organizations in a timely manner, a stringent reporting schedule must be adhered to. The optimum technical report is one that contains as much pertinent information as possible in the shortest period of time. Over the years at the Air Force Flight Test Center, this procedure has developed into a highly efficient schedule that allows 90 calendar days from the final test to report approval. Since maintaining a schedule is key to report accomplishment, the authors must be given continual support throughout the process. This support must come from all sources including management, data processing, coauthors, pilots and maintenance personnel.

Some problems which reduce report quality are: (1) not specifying reporting requirements early (during the planning phase), (2) attempting to develop a final

technical report while expecting the author to engage in active follow-on testing, or planning for new test programs, (3) trying to consolidate too much information under one cover, when separate discipline reports would be more tenable, (4) not applying adequate management emphasis early and continually to the reporting process, (5) trying to summarize large volumes of information in the body of the report when it could be contained in an appendix or referred to in the list of references, (6) trying to explain with voluminous words that which could be presented much more succinctly in tabular or pictorial form, and (7) not paying adequate attention to details. A proposed schedule to accomplish the reporting task is presented in Figure 6.



1. Include detailed reporting requirements in test plans.
2. Establish editing support requirements.
3. Determine type report and format. Preparation of preliminary sections, (e.g., Introduction, Test Methods, Appendices, etc). Get approval of distribution list from program management.
4. Determine cutoff date, initiate report tracking process.
5. Report preparation with guidance and tracking by technical and project supervisors.
6. Draft submitted to immediate supervisor.
7. Assessment by supervisor and rework as necessary. Distribute draft report at least 5 days prior to coordination meeting.
8. Coordination meeting.
9. Rework as required after coordination meeting.
10. Final coordination/approval by management.
11. Final approval. Send copy of approved report to acquisition program management office. Prepare report for printing.
12. Printing process.
13. Distribute printed report in accordance with a previously approved list.

Figure 6 Technical Report Schedule

6.4.2 Technical Report Guide

The details on report types, scope and content should be established early in the planning phase and spelled out in the test plan. Prior to or during the test phase, the author should establish the editing and support required (e.g., illustrations, word processing, etc.) to complete the report and finalize the report type, format and schedule.

Editing support (if available) should be requested early in the reporting process to:

a. Initiate the report status tracking process.

b. Provide report writing guidance.

c. Provide distribution requirements and restrictions.

d. Provide general consultation.

Many of the technical aspects of a report cannot be completed until data gathered during the flight tests are finalized and analyzed. However, the "boiler plate" (e.g., Preface, Introduction, Table of Contents, Test Item Description,

References, Test Methods and Procedures, and appendix material) can and should be accomplished during testing, for that matter, even before testing starts. Immediately upon completion of testing, the author, in conjunction with management, should determine the cutoff date and report schedule and initiate the tracking process.

6.4.3 Establishing Milestones and Deadlines

Milestones should be established to ensure that technical reports are approved and distributed within deadlines. The key milestone that initiates the process is the cutoff date, which is normally the date of the last flight or test. The cutoff date should be approved by the appropriate technical supervisors and managers. Once this is established, it and other milestones should be documented by the report tracking process on a weekly basis. Reports should be prepared, reviewed, and approved within the deadlines.

6.4.4 Outline

An outline is essential and should be the first task accomplished. The more detail contained in the outline, the better, and once accomplished, essentially becomes the Table of Contents of the report. Using the outline, the report can be accomplished in structured increments that lead to a successful and timely completion of the final document in the most expeditious manner. The outline should be discussed in detail with the technical supervisor who has direct responsibility for the content of the report. This supervisor should apply continual management emphasis to ensure constant progress and to prevent stalemate, stagnation, overreporting, or tangential reporting. The degree of management emphasis required is usually inversely proportional to the report writing experience of the author. Frequent discussions between the author and supervisor help keep the report on track and preclude false starts. This also minimizes the time required for review of the draft by the supervisor, who is responsible for the accuracy of the technical content of the report.

6.4.5 Coordination Meeting

As soon as an assessment can be made of the rework required after this first review, a coordination meeting should be scheduled to obtain comments from interested parties. This is one of the most important milestones of the report writing process. All pertinent parties with a vested interest in the report content should be invited to comment at the coordination meeting. All reviewing and approval officials should be represented at this meeting to make it meaningful. Nothing demoralizes an author more than to learn after coordination that the report was not really coordinated.

Coordination copies of the report should be distributed to the attendees at least five working days prior to the meeting to allow sufficient time for complete review. These copies should be as complete and as close to the final product as possible. It should be double-spaced on numbered line paper to allow room for penciled changes and to expedite reference to a given sentence. The pages should be numbered. Having typed the report on a word processor is extremely helpful when subsequent changes are required.

In the interest of timing, changes to the report should not be entertained after the coordination meeting unless something is determined to be technically in error. Here is where preplanning pays off. A change in format or organization at the coordination meeting can result in a major rewrite and consequently a late report.

Authors should leave "pride of authorship" outside the door during coordination and assume that all parties are presenting constructive criticism with the sole objective of improving the report. Incidentally, I have never attended a coordination meeting that didn't result in improvements in a report, no matter what the experience level of the author.

During the coordination meeting the author and supervisor should make a special effort to insure that all the agreed upon changes and corrections are properly documented and the exact wording is understood. This will expedite the rework after the meeting. Time should not be spent during the meeting in making administrative corrections. Those can be obtained from the coordination copies after the meeting and integrated by the author or an editor. The individual coordination copies should be retained until final coordination and approval is completed in case reference is required.

6.4.6 Final Coordination and Approval

After the coordination meeting, the report is reworked in accordance with the notes taken during the meeting. All final plots, photographs, tables and line drawings should come together by the time the report has reached the immediate supervisor in the final coordination cycle.

By the time the report has been reviewed by the immediate supervisor, all further reviewers should be able to read for content, knowing that misspelled words, typographical and administrative errors have been eliminated and that the format and content is in accordance with local requirements. The author must be continually alert for lack of progress of the final review and approval cycle, especially with classified reports, which can be overlooked in a safe for a few days.

6.4.7 Report Printing and Distribution

The author should make a copy prior to starting the final review and approval cycle so quality control review can continue and to develop a collating guide for printing after the report is approved. Upon approval, a signed copy should immediately be sent to the acquisition management office. This gets the approved information to them without waiting for the printing process.

With the collating guide complete, the report can be delivered to the print plant within one or two days after approval. Depending on the process and backlog, printing usually can be accomplished in two to three weeks. Distribution, in accordance with a previously approved distribution list, should be accomplished immediately after printing.

7. REFERENCES

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8. APPENDIX

8.1 Climatic Laboratory Tests

The Climatic Laboratory is normally used for the initial phase of climatic tests. Generally, the primary objective of these tests is to determine the capability of a weapon system, including support equipment and attendant crews, to accomplish its design mission under selected extreme environmental conditions (to the extent possible in a laboratory). More detailed specific objectives to be satisfied on a test-by-test basis are as follows:

a. Identify any potential climatically related safety of flight deficiencies.

b. Verify and determine the adequacy of technical order procedures to support their intended ground operational and maintenance functions.

c. Determine adequacy of support equipment and evaluate its compatibility with the man-machine interfaces.

d. Evaluate human factors related tasks during test vehicle operation and maintenance activities.

e. Provide data to update the overall engineering analysis on a particular weapon system.

f. Establish subsystem baseline data under controlled conditions.

g. Develop workaround procedures for problems encountered.

Component and subsystem qualification tests in extreme conditions should have been completed prior to testing of the complete air vehicle and, therefore, are not usually included in Climatic Laboratory tests. However, components/subsystems, which have been identified as marginal or critical for extreme climatic operation during qualification testing, will be subject to special attention during Climatic Laboratory testing. Problems which are identified during Climatic Laboratory testing should be documented and immediately deferred to the acquisition program management office for corrective action. Major deficiencies should be corrected, if possible, prior to deployment to actual environmental test sites, so that these corrections can be evaluated. If deficiencies are not corrected, workaround procedures will be used, where possible. Potential safety of flight problems, however, must be resolved prior to further deployment.

All support equipment should be conditioned for the ambient temperatures involved during the first tests in accordance with the appropriate technical orders prior to shipment to the Laboratory. The appropriate technical orders should at least be validated prior to use in the Climatic Laboratory. This effort might be limited to a "walk through" of some procedures in the All-Weather Operations section of the technical orders.

A baseline corrosion inspection should be conducted prior to entering the Laboratory. If the weapon system is new and has recently been accepted, the acceptance inspection can fulfill this requirement.

Prior to deployment to the Climatic Laboratory, the weapon system should be configured as close to the production model as possible. Any deviations from production configuration should be noted and these deviations corrected as soon as possible. The most appropriate time for these corrections is usually between deployments to the various test sites when the test vehicle can be returned to the airframe manufacturer's facility to correct major deficiencies and update the configuration. Quick response "fixes" should be incorporated in the Climatic Laboratory. An evaluation of the effectiveness of the "fix" can thus be made prior to deployment to an actual weather test site. However, the installation and subsequent test of the "fix" could entail an extension of the stay in the Climatic Laboratory. That possiblity would have to be weighed against the Laboratory's next test commitment as well as that for the test vehicle.

Test schedules for the Laboratory test chambers and facilities are prepared, coordinated, approved, published and revised, by the Laboratory's Project Control Office. Changes in test requirements must be submitted to this office on a timely basis so that these requirements can be satisfied. If the daily test schedule requires activities other than environmental control after duty hours, or on weekends or holidays, provisions should be made for necessary support through the Project Control Office at the earliest possible time. Some second shift effort can be accomplished if advance arrangements are made so that a Laboratory test advisor can be present. A test advisor represents the Climatic Laboratory from a support standpoint and is the liaison between the test team and the Laboratory. Activities which are usually not allowed on a second shift include aircraft engine operation and refueling or defueling operations.

The Task Force Commander, or a person appointed by him, usually a test conductor, is the official point of contact with the Climatic Laboratory Project Control Office. At the termination of testing the Task Force Commander will be asked to fill

out a Test Evaluation Form provided by the test advisor. During test, the test conductor is in control of the entire operation.

Functional tests of an air vehicle's systems and its support equipment should be conducted to the fullest extent possible within the scheduled time constraints and limitations of the Laboratory and test setup. Some activities will involve a degree of simulation and some technical order procedures will require modification to be compatible with the limitations of the Laboratory.

Limitations and constraints encountered in the Laboratory include:

a. The test vehicle cannot be taxied or flown.

b. Engine power settings and operating times are reduced because of air makeup capability.

c. Helicopter rotor torque is reduced and there is unnatural circulation.

d. At low temperatures the air has a high water content due to the inability of the refrigeration system to remove water vapor.

e. High power transmitters cannot be operated.

f. Avionics systems are limited to functional checks. Because the systems can not be operated, system performance cannot be obtained.

Tiedown, test, post-test maintenance and a functional check flight comprise the major elements of the Climatic Laboratory work breakdown structure. Usually one to two weeks are required for the tiedown process for a complex installation, eight to twelve weeks for test, and one week for post-test activities in preparation for ferrying.

8.1.1 Test Requests

Requests for major system testing in the Climatic Laboratory main chamber require lead time of up to one year. Requests for testing of smaller items in the main chamber require 90 days lead time and a minimum of 30 days is required for use of a small test chamber. Careful coordination is required if more than one test is conducted in the laboratory at the same time.

For emergency tests, Climatic Laboratory personnel will immediately review each request for test support on its own merits, and will consider providing support on an "as available" basis, making every effort to cooperate with the requestor.

A request for testing should include the following information, some of which is the responsibility of maintenance and other support organizations:

a. Description of the test item, to include dimensions, weight and load carrying capability of tiedown points.

b. Number of engines to be operated and their airflow requirements.

c. Any hazards associated with handling or operating equipment.

d. Radio frequencies associated with the equipment which might require a frequency authorization.

e. Test objectives and general plan of the test.

f. Total floor area to be occupied by the test item and support equipment, and area adjacent to the test item required for work operations.

g. A tentative list of military and civilian personnel who will be present to conduct tests. This list should include name, duty title, rank or grade, security clearance, and estimated time of arrival and duration of stay at the facility.

h. Date test item will arrive at Eglin AFB, Florida.

i. Priority of the test.

j. Security classification of the test item, test program and test results.

k. Support expected, which normally includes:

(1) Fuel, oil, lubricants (specify types, grade, etc., including arctic requirements).

(2) Support equipment, such as heaters, jacks, cranes and tow vehicles. Some items not available at the Climatic Laboratory can be obtained on an on-call basis from other organizations. Many times this equipment is not available and it is better to provide or arrange for your own equipment.

(3) Instrumentation design and fabrication. Specify all parameters to be measured by the Laboratory including ranges and accuracy required.

(4) Installation and maintenance of special devices, such as exhaust ducts for air breathing propulsion units.

(5) Water spray frames. Specify rate of precipitation and area to be covered by spray.

(6) Solar radiation. Specify radiation intensities and area to be radiated.

(7) Projectile trap for gunfiring tests.

(8) Still, motion picture and video coverage.

(9) Cold weather clothing. Specify number of suits of clothing required. The Laboratory provides arctic gear including boots, trousers, jackets, gloves and caps. Lockers are available for storing this gear.

(10) Electrical power services. Specify kinds of power, voltage and amperes, amount of frequency regulation, types of plugs and receptacles desired, and where it should be installed.

(11) Machine and instrument shop service.

(12) Amount of storage space desired and type, such as outside, inside, classified or unclassified.

(13) Office space and equipment. Information on this item should include:

(a) Number of people requiring accommodations.

(b) Number of desks and chairs.

(c) Number of conference or similar tables and chairs.

(d) Number and type of filing cabinets.

(e) Any additional or special furniture requirements.

(f) Telephones required.

(14) Space and power for portable data facility.

It is necessary that an advance planning meeting be held at least three months in advance of the first scheduled test with representatives from the sponsoring acquisition program management office, testing agencies and the airframe manufacturer in attendance. This meeting should be arranged by the Task Force Commander through the Climatic Laboratory to provide test personnel with the opportunity to discuss items in the Program Introduction document and in particular:

a. Review, define, clarify and reach agreement on the test support requirements. It should be possible at this meeting to identify those requirements which can be satisfied by resources at Eglin AFB, those which will require procurement action by Eglin AFB, and those which the sponsoring or test agencies may be required to provide.

b. Identify and resolve any support problem areas.

c. Become familiar with the details of Climatic Laboratory operation.

A second meeting may be necessary approximately one to two months in advance of the test to resolve any remaining support problems and to finalize the Statement of Capability.

8.1.2 Safety

Considerable emphasis is placed on safety in the Climatic Laboratory. Each using test team is thoroughly briefed on plant protective systems and inherent hazards. Operating Instructions have been developed to cover hazards peculiar to the operations inside the main chamber. These hazards include poor visibility, congested work areas, slick surfaces, high noise environment, risk of frostbite, etc. These Operating Instructions can be obtained prior to conducting a test.

8.1.3 Test Vehicle Tiedown Phase

The test vehicle is secured within the Laboratory in such a way as to allow optimum operation of all systems. This includes engines, auxiliary/emergency power units, landing gear, control surfaces, rotors, guns, radar and inertial navigation

system alignment. The test vehicle may be installed on jacks, restrained, and suitable exhaust ducting installed for engines, auxiliary/emergency power units, and certain ground support equipment. Greased skids are used under selected jack pads to allow for thermal expansion and contraction of large air vehicles. Helicopters are tied down with the skids on crossbeams and tail boom restraints. Test vehicles with landing gear are tied with restraining beams attached to the structure.

The integrity of the tiedown system is verified during the first test and confirmed after each succeeding test. Tiedown cable tension is adjusted continually during the entire test program because of thermal expansion and contraction with changing temperatures.

The design and fabrication of the tiedown fixtures, ducting, radar shields, bullet catchers, etc., is the responsibility of Climatic Laboratory personnel. The airframe manufacturer should be tasked to design and fabricate the interface attachment fixtures and provide required technical data on such items as engine thrust and mass airflow, tiedown stress points, etc. Close coordination is required between Climatic Laboratory and test team personnel to obtain the optimum tiedown system. It is the responsibility of the climatic test engineer to act as liaison between airframe manufacturer and Laboratory personnel and to assure that the tiedown system does not interfere with the positioning of support equipment or operation of any subsystem (e.g., flight control surfaces, landing gear, etc.). During the tiedown period, the data van, the Laboratory data acquisition system, and the test communications systems should be set up.

8.1.4 Test Phases

The Climatic Laboratory test phases can provide full exposure to controlled climatic ground extremes such as temperature, humidity, solar radiation, rain, ice, etc. Environmental conditions to be considered during Climatic Laboratory tests include the following:

a. 70-degree F(21-degree C) baseline tests before and after each extreme environmental sequence.

b. Cold ambient temperatures in 10- to 15-degree F (3- to 8-degree C) decrements to the system specification limit and -40/-60-degree F (-40/-51-degree C) temperature cycles.

c. 90/125-degree F (32/52-degree C) diurnal cycles with simulated solar radiation/heating.

d. Relative and absolute humidity extremes.

e. Tropical rainfall (tap water temperature) at an ambient air temperature of 85 degrees F (29 degrees C) including wind up to 35 knots.

f. Engine water ingestion.

g. Freezing rain and artificial icing.

h. Ground icing.

These tests should be organized to minimize the logistics effort involved in moving the rain frames, wind machines, solar arrays, etc., and be consistent with safety requirements.

8.1.5 Temperature Stabilization

The test system must undergo a period of thermal soak at each ambient temperature to stabilize the test system within ± 5 degrees F ($\pm$ 2 degrees C) of the aim test temperature. Determination of a stabilized condition can be made by monitoring the fuel, oil, hydraulic fluid, and metal mass (fuselage structure) temperatures. The controlling temperature will vary depending on the initial conditions. For instance, if stabilization follows a large ambient temperature change, the engine oil reservoir temperature will probably be first to stabilize, followed by the hydraulic reservoir, the metal mass and large fuel mass, respectively (Figure 7). On the other hand, if the test system is being reestablished at a given temperature after an engine run, the engine oil or hydraulic fluid may be last to restabilize.

The rate of change of temperatures can be increased by lowering the Laboratory ambient temperature approximately 10 degrees F (3 degrees C) below the aim stabilization temperature. The test system temperature must be closely monitored and when it approaches the aim temperature, the ambient temperature should be returned to the desired value. This procedure significantly reduces soak time. An example of this can also be seen in Figure 7 where the desired ambient temperature was 0 degrees F (-18 degrees C). Time for test system components to reach ambient temperature will vary as a function of mass, heat paths, materials, etc. Time to reach stabilization at a given ambient temperature should be recorded as a guide in determining required soak times at the other deployment sites where it will be impractical to monitor temperature time histories. Integrity of data obtained and achievement of objectives should be verified after testing at each test temperature before altering the climatic condition.

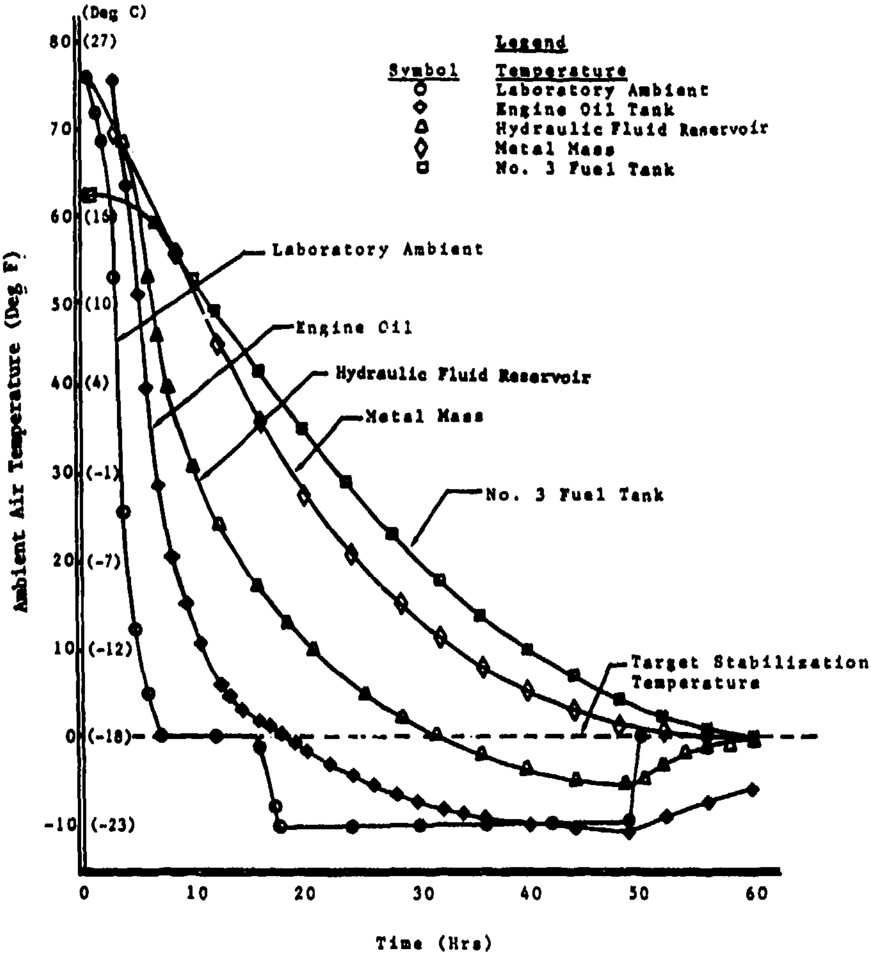

Figure 7. Mass Temperature Stabilization Time History

Temperature gradients should not exceed 10 degrees F (6 degrees C) per hour to avoid test system thermal shock. As the Laboratory is lowered to the cold ambient temperatures, care must be taken to ensure that the engine exhaust duct plugs (located outside the Laboratory) are in position and removed only during engine runs. In addition, a slight positive pressure must be maintained in the Laboratory during testing. This precaution is necessary to prevent moist outside air from entering the exhaust ducts and freezing within the engine, which could immobilize the turbine/compressor.

Engine run times and power settings will be influenced by the capability of the Laboratory to provide makeup air to replace that used and exhausted by the engines. Procedures must be established with air makeup personnel to inform the test conductor when their capability for maintaining test temperatures is approaching exhaustion. In addition, the pilot must inform the air makeup personnel prior to significant engine power changes.

8.1.6 Initial 70-Degree F (21-Degree C) Baseline Tests

An abbreviated initial test run is accomplished at Laboratory ambient temperature to verify the integrity of the tiedown and ducting installation, functionally test the instrumentation system and to familiarize the test team with the test operation. The first baseline tests are conducted after the Laboratory ambient and test system temperatures are stabilized within ± 5 degrees F ($\pm$ 3 degrees C) of 70 degrees F (21 degrees C). It should be noted that 70 degrees F (21 degrees C) has been used historically, but another temperature such as standard day sea level could be used

equally as well if a requirement exists. These tests are conducted before the first extreme climatic condition tests to obtain baseline data on subsystem operation. Examples of information obtained includes:

a. System warm-up times.

b. Control surface rates.

c. Zone and surface temperatures.

d. Fuel, hydraulic fluid and airflow rates.

This data will be used for comparison with that obtained at the extreme climatic conditions and with the data obtained during the next baseline tests to determine any degradation in subsystem performance.

8.1.7 Cold Temperature Tests

Testing at the most critical temperature extremes should be done first after the baseline test (e.g., if the weapon system were to be deployed to the arctic after the Laboratory, testing at the cold extremes should be done first). This approach will allow more time for development of workaround procedures and correction of deficiencies prior to deployment to the arctic.

For the tests conducted at the cold extremes, the Laboratory ambient temperature would be lowered in -10-degree F (-6-degree C) decrements and stabilized at several progressively lower temperatures. These test temperatures were determined by experience with fluid viscosity increases, fluid leakage problems, changes in subsystem or support equipment usage, etc., and should be approximately 0, -10, -20, -30, -40, -50, and -60 degrees F (-18, -23, -29, -34, -40, -46, and -51 degrees C). These temperatures allow testing to the most severe requirements of MIL-STD-210, Ref (4). The most severe condition may depend on the air vehicle specifications.

The 0-degree F (-18-degree C) test run is accomplished when the test system temperatures are stabilized within ± 5 degrees F ($\pm$ 3 degrees C) of the desired ambient temperature. After completion of the tests at this temperature, the procedures are repeated at the other required ambient temperatures. Tests at intermediate temperatures or at increasing temperature levels may be required if a problem is discovered, and it is necessary to pinpoint the temperature at which the problem occurred. If testing is sustained at -40 degrees F (-40 degrees C) and below, the capability to operate degrades significantly.

In the event a system is deficient at extremely cold temperatures, workaround procedures are frequently required to continue with the test. Normally this procedure would involve the application of localized heat to specific components. The requirement to apply heat is an added burden to operations in extreme environmental conditions. The deficiency and the workaround procedures should be documented with the recommendation for aircraft component modification to allow heat free operation if required for combat alert.

Condensation may form when moving a test system component from a cold environment to a warmer environment. This condensation will freeze when the component is returned to the cold.

During cold temperature tests, particular attention should be paid to: warm-up times required to achieve safe takeoff, flight control movement, hydraulic leaks, capability of hand pumping auxiliary power unit or jet fuel starter accumulators, deflated accumulator precharge, gear struts, and tires on the test vehicle and support equipment, and man/support equipment/test vehicle interface problems.

On completion of the final run at the cold temperatures, the Laboratory ambient temperature is raised to 70 degrees F (21 degrees C) and the test system temperature stabilized. It should be noted that ice formation on the cold concrete floor of the Laboratory during this process is extremely hazardous. Consequently, two days should be allowed for the Laboratory to "dry out". The test system should be inspected for any residual damage, (e.g., cracks, leaks, etc.) which occurred during the low temperature tests.

8.1.8 Second 70-Degree F (21-Degree C) Baseline Tests

Test runs are again accomplished at the baseline temperature and the data compared to the initial baseline results. Discrepancies are noted and investigated to determine if they are a result of subsystem damage or deterioration resulting from low temperature operation. When a component is returned to the airframe manufacturer for repair, a failure analysis should be requested. If some deficiencies dictate, corrective action should be taken and an additional baseline test conducted to compare with the baseline results obtained after the hot temperature tests.

8.1.9 Hot Temperature Diurnal Cycle Tests With Solar Radiation

Climatic Laboratory personnel will construct the required solar arrays for a given test program. These arrays are fabricated to cover the prescribed surface areas

of a given test vehicle/equipment and are very expensive, so the requirements for their use should be scrutinized carefully. Considerable effort is required to calibrate, install and remove an array from the Laboratory, so the logistics and sequence of these tasks must be carefully planned to minimize the impact on the test schedule. The radiation intensity is measured by a pyrheliometer and is controlled to a given surface temperature at some point on the test vehicle.

It should be noted that MIL-STD-21Ø, Ref (4), radiation intensities are for a natural environment and do not apply inside the Laboratory because the solar simulator and Laboratory ceiling will not permit energy reradiation to deep space. For instance, the MIL-STD-21Ø requirement was 1Ø5 watts per square foot (113Ø watts per meter^2), but only 5Ø watts per square foot (538 watts per meter^2) were required to reach the allowable temperature of 2Ø3 degrees F (95 degrees C) on the black fiberglass radome of the E-3A. A discussion of this phenomenon can be found in Ref (19).

For the hot diurnal cycle tests, the solar array is installed and the Laboratory ambient temperature is stabilized at 9Ø degrees F (32 degrees C). A typical cycle, including solar radiation, is conducted as shown in Figure 8. During these tests, particular attention should be paid to aircraft engine and auxiliary and emergency power units, environmental control systems and ground cart cooling capability, zone and surface temperatures, and systems with automatic overheat/shutdown features.

Note: Solar radiation approximately 50 Watts/Ft^2 (538 Watts/M^2). Antenna pedestal upper surface temperature controlled to 203 $\pm$5 Deg F (95 $\pm$2 Deg C).

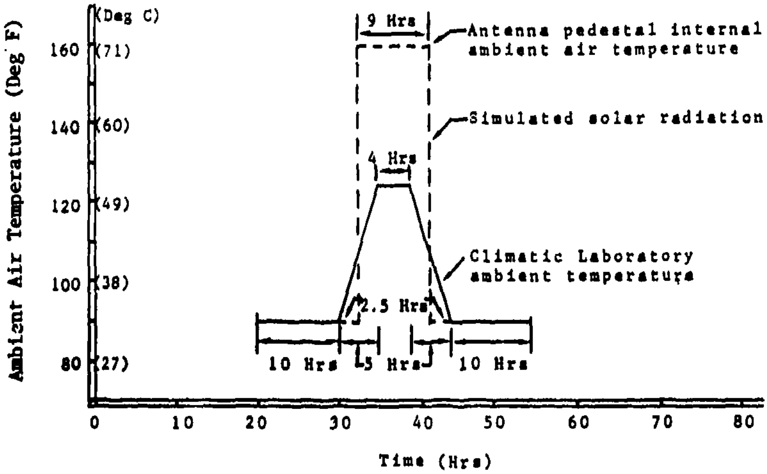

Figure 8. Typical Hot Temperature Diurnal Cycle

8.1.1Ø Relative Humidity Tests

The first part of the relative humidity test is similar to the 9Ø-/125-degree F (32-/52-degree C) diurnal cycle test condition. In addition to solar radiation, the relative humidity should be controlled to the conditions specified in MIL-STD-21Ø. The second portion of the test is done at high relative humidity during which the aircraft is cooled down and then the ambient temperature increased so that condensation will form on the "cold" surfaces. This test simulates a cold soaked aircraft descending and landing in a tropical climate. A typical temperature/humidity profile is presented in Figure 9. Inspections should be made for moisture on avionics component racks and water accumulation in lower parts of the air vehicle.

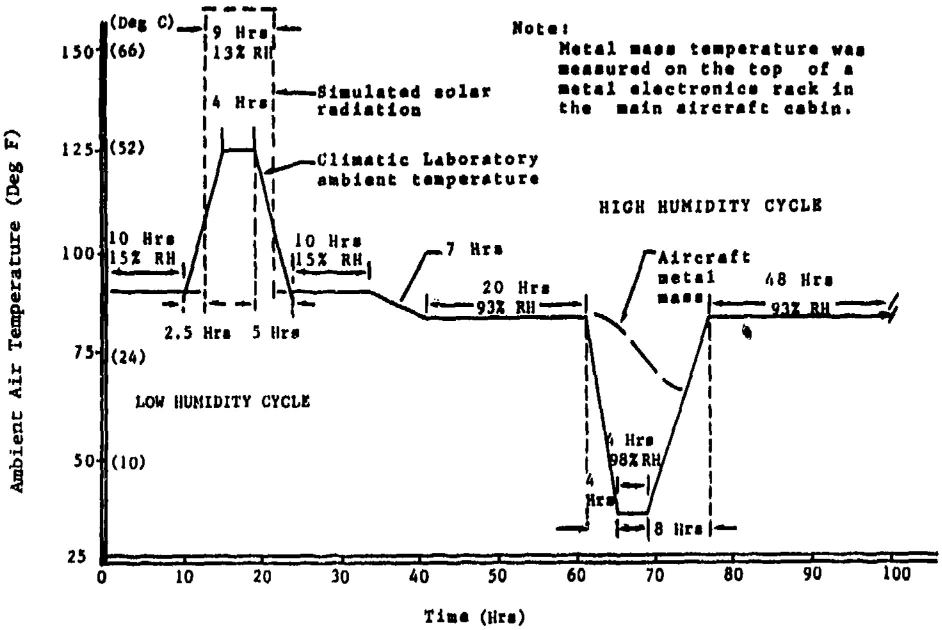

Figure 9. Typical Relative Humidity Cycle

8.1.11 Tropical Rain Tests

For tropical rain tests, the rain frames are installed and the Laboratory ambient temperature is stablized at 85 degrees F (29 degrees C). Rainfall and wind are applied to the test system as specified in the air vehicle specification. A typical rainfall application is shown in Figure 10. Laboratory personnel will fabricate, install and calibrate the rain frames. These frames can be suspended over most of a given test system and deliver water from 1 inch (2.5 centimeters) per hour to at least 15 inches (38 centimeters) per hour. As with installation of solar arrays, sufficient time must be allotted for installation, calibration and removal of the rain frames. The Climatic Laboratory also provides wind machines with attached circular rain frames to simulate blowing rain up to 35 knots. Consideration should be given to positioning these machines so that blowing rain will impinge on panels, inlet and exhaust ducts, doors, etc., to determine the extent of leaks and effect of water accumulation. Inspections should be made for entrapped moisture, leaking seals, plugged drains, etc.

8.1.12 Freezing Rain Tests

The freezing rain tests are normally conducted sequentially with the tropical rain tests to minimize rain frame logistics and installation time. The most realistic test simulates a light freezing rain at an ambient temperature slightly above freezing, with the rain continuing as the ambient temperature decreases below freezing, simulating a cold weather front passing. The resulting condition causes water to freeze during migration through the structure. This may block drain holes and cause internal ice buildup. For this test, the ambient temperature of the test vehicle is stabilized at 35 degrees F (2 degrees C) and light rain is applied at approximately 0.4 inches (1.0 centimeter) per hour for approximately two hours. During this time, wind machines with attached circular rain frames simulate blowing rain at 15 knots on critical areas of the test system. The ambient temperature is lowered to 24 degrees F (-4 degrees C), over a two-hour period, while the wind and rain continue. During this period, glaze ice accretes approximately one-half inch (1.3 centimeters) thick on the surface of the test system, including the windscreen, flight control surfaces, landing gear, pitot-static system, engine inlet, and support equipment. After the wind and rain are stopped, the test system is stabilized at 24 degrees F (-4 degrees C), and inspections are conducted to determine the effects of ice on various subsystems. This inspection is hazardous because of the slick surfaces on and around the test system. During this inspection consideration should be given to the following:

a. Pitot-static system blocked.

b. Seals tearing as panels or canopy are opened.

c. Angle-of-attack probe affected.

d. Potential foreign object damage from ice buildup around engine inlet and intake.

e. Ice buildup around canopy frame.

f. Drains blocked/ice accumulation.

g. Ice accumulation around moving surfaces (flight control restrictions).

h. Human factors problems opening panels/standing on slick surfaces.

i. Water flowing in cracks then freezing.

Ethelyne glycol deicing fluid cannot be used inside the Laboratory because the drains flow into an adjacent bay and cause adverse environmental effects. To deice the vehicle properly, the ambient temperature of the Laboratory should be raised above freezing until all the ice is melted. Portable heaters may be used to speed up this process.

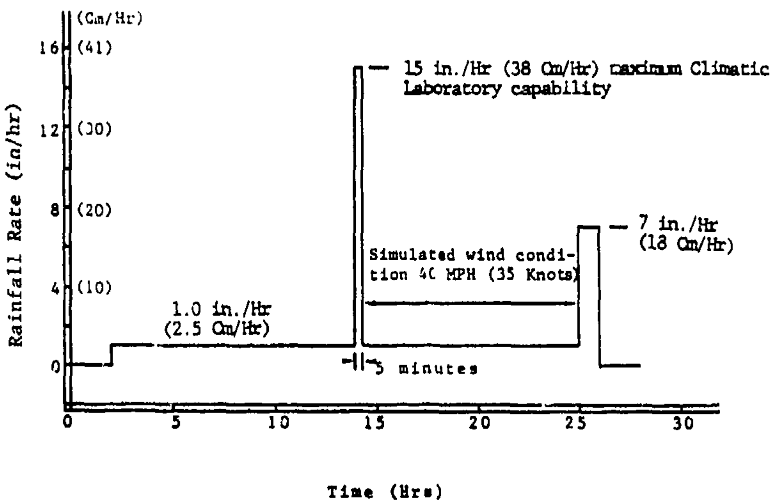

Figure 10. Rainfall Rate Used for Climatic Laboratory Tests

8.1.13 Engine Water Ingestion Tests

Engine water ingestion tests are conducted by spraying liquid water into the engine inlet at total mass flow ratios recommended by the airframe manufacturer or engine specifications. The objective is to simulate an aircraft flying or taking off through a rainstorm or water on the runway deflected into the engine inlet. The water vapor in the air that could condense into liquid as the pressure decreases in an inlet should be calculated and included in the total water being ingested by the engine. Charts were developed, depicting the water/air ratio for variables of rainfall rate, relative humidity, altitude, and ambient temperature, Ref (15). The pilot and test engineer should be alert for engine operating abnormalities during this test (e.g., reduced exhaust gas temperature, unstable rpm, and compressor stall).

8.1.14 Third 70-Degree F (21-Degree C) Baseline Tests

The third set of baseline tests is conducted with the test system stabilized at 70 degrees F (21 degrees C). These test results are compared with the previous baseline test results to determine the permanent adverse effect of the previous climatic extremes on airframe/subsystems. Discrepancies should be noted and investigated to determine if they are climatically related. It is possible and sometimes warranted to go back to a test temperature and recheck problem areas prior to removing the test system from the Laboratory. After all tests are completed with the test vehicle tied down, the restraints and ducting are removed so that towing, tailhook deployment tests, can be conducted.

8.1.15 Post-Test Phase

After all tests are completed, the test system is removed from the Laboratory, inspected thoroughly, readied for flight (if required), flown on a functional check flight and ferried to its next destination. This could be to the airframe manufacturer's facility for updating in preparation for deployment to other test sites. Data should be gathered during the functional check flight to determine the effects of climatic extremes on subsystems that could not be detected during static tests in the Laboratory. An inspection for corrosion potential should be conducted after the tests with high humidity, rain and water ingestion. This is time consuming, since many panels require removal, but is a very important inspection. Areas of prime interest include flight control access areas, antennae, avionics racks, hinges and panels on the bottom of the test vehicle.

8.2 Instrumentation Parameters for Testing in Extreme Climatic Conditions

Selection of specific instrumentation parameters is based on past climatic test experience and particular engineering requirements for a specified weapon system to be tested. A generic instrumentation parameter list for testing in extreme climatic conditions is contained in Table 6.

Table 6

Generic Instrumentation Parameters for Testing in Extreme Climatic Conditions

General Operating Parameters (Flight Test Only)
- Airspeed
- Pressure altitude
- Mach number
- Cockpit or cabin pressure
- Outside air temp or ram air temp
- Three axes acclerations (N_x, N_y, N_z)
- Sideslip, bank and pitch angles

Engines
- Low pressure (N_1) and high pressure compressor(N_2) rpm (each engine)
- Power lever angle (each engine)
- Exhaust gas temp (each engine)
- Engine oil pressure and temp

Environmental Systems

Bleed Air System
- Bleed air supply temps and pressures (1 temp, 1 press per engine)
- Primary heat exchanger (HX) inlet and outlet temp (1 each)
- Secondary HX inlet and outlet temp (1 each)
- Fuel pressurization air temp
- Gun gas purge air temp

Air Cycle System
- Venturi inlet air temp
- Environmental Control System (ECS) compressor inlet and outlet temp
- Regenerative heat exchanger inlet temp (hot side)
- ECS turbine inlet and outlet temp (1 each)
- Water separator outlet temp

Supply Air Systems
- Cabin supply air temp
- Crew compt supply air temp
- Cargo compt supply air temp
- Avionics bay supply air temps (1 temp each supply line)
- Radar forced air cooling supply air temp
- Cabin antifog supply air temp

Forced Liquid Cooling - Radar and Avionics
- Liquid/air HX liquid inlet and outlet temp (1 each)
- Cooling loop liquid temp
- Fuel loop fuel temp - sump outlet
- Intercooler coolant loop - pump outlet temp

Compartment Air Temperature Survey
- Cabin ECS inlet and outflow air temp (1 each)
- Pilot and copilot head, waist, and foot air temp
- Crew compt ambient air temp (1 each bunk area, 1 each seat)
- Cargo compt ambient air temps (6 minimum at selected locations)
- Avionics equipment bay ambient air temp (Number and location as required, depending on configuration of the bay)

Temperature Control System
- Cockpit temp control switch position - auto and manual
- Crew compt temp control switch position - auto and manual
- Cargo compt temp control switch position - auto and manual
- Equipment cooling flow control valve position

Equipment Environment (General)
- Head-Up Display (HUD) surface temp
- Cockpit compt surface temp
- Under glareshield ambient temp
- Cabin console ambient temp
- Various structural surface temp - vertical tail, rudder inboard, fin root, stabilator bearing, wing leading edge.
- Windshield and canopy surface temp (minimum of 4 on windshield, 4 on canopy)
- Engine/auxiliary power unit/Jet fuel starter compts ambient air temp (2 minimum per compt)
- Cockpit humidity
- Black globe temp
- Cockpit total radiation heat load
- Cockpit dew point

Critical Environmental Soak Parameters
- Fuel tank internal temp - largest fuel mass
- Engine oil tank temp
- Auxiliary power unit oil sump temp
- Jet fuel starter oil sump temp
- Accessory gear box sump oil temp
- Battery case temp
- Engine metal mass temp
- Hydraulic fluid temps (ref to hydraulic instrumentation list)
- Airframe metal mass temp

Ambient Soak Parameters (Climatic Laboratory only)
- Nose ambient temp
- Left wingtip ambient temp
- Right wingtip ambient temp
- Top of vertical tail ambient temp
- Main wheel well ambient temp
- Nose wheel well ambient temp

Electrical Systems

- Generator circuit breaker position (1 per breaker)
- Bus tie breaker positions (1 each tie)
- Total current-generator(s) output (all 3 phases)
- Real current load(s) for each generator (all 3 phases)
- Voltages, all phases, for main and emergency alternating current (ac) bus
- Each generator frequency (all 3 phases)
- Permanent magnet generator voltage
- Permanent magnet generator frequency
- Constant speed drive charge oil pressure
- Constant speed drive oil temp (inlet and outlet of HX)
- Constant speed drive/generator input shaft speed
- Battery and battery charger output voltage and current
- Emergency generator motor hydraulic pressure
- Voltage and current output from each Auxiliary power unit-driven generator

Hydraulic System

General - each separate hydraulic system

- Engine driven and auxiliary pump inlet and outlet pressure
- Hydraulic reservoir pressure and temp (1 each per reservoir)
- System downstream pressure at coupling/junction (1 per hyd sys)
- Engine N_2 rpm (for engine driven hydraulic pumps)
- HX inlet and outlet temp - 1 each (hot tests)
- Accumulator precharge pressure

Hydraulic Subsystems

- Flight controls (one each rudder, ailerons, elevators, spoilers, and speed brakes)
  - Surface position
  - Each actuator inlet press and temp (cold tests)
  - Stick/control column position
  - Rudder pedal position (each rudder)

- Landing gear
  - Retract actuator inlet pressure (nose and main gear)
  - Landing gear position (1 each gear)
  - Landing gear handle up and down indication (discrete)

Flaps/Slats
Drive motor inlet pressure (1 each motor)
Flap/slat position (1 each slat/flap section)

Steering System
Actuator inlet pressure and temperature
Nosewheel position

Air Refueling Receiver System
Slipway door actuator inlet pressure
Nozzle latching toggles actuator inlet pressure
Slipway door and latching toggle position (1 each)

Brakes
Brake puck position
Brake line pressure
Torque to rotate tires (large strap wrench around one tire with lever arm and force gage)
Brake stator or assembly mass temp

Special Aircraft Hydraulic Systems

Auxiliary Power Unit/Jet Fuel Starter
Accumulator pressure (1 each)
Start motor inlet pressure (1 each)
RPM - turbine (1 each)
Accumulator fluid temp - 1 each (cold only)
Exhaust gas temp (1 each duct)

Weapons Bay Doors/Rotary Launchers/Rotary Guns/Radar Driven Gun Turrets/Air Refueling Boom
Position (each item)
Actuator/motor inlet pressure (each system drive)

<u>Fuel Systems</u>

General - Each Tank
Pneumatic pressure to fuel tank (from engine bleed air system)
Fuel quantity
Fuel pump discretes - each pump (ON/OFF)
Engine inlet fuel pressure and temperature (each engine)
Engine inlet fuel flow (each engine)
Fuel temp HX in/out, fuel pump inlet and tank (1 each)
Transfer or crossfeed manifold pressure
Aerial refueling manifold pressure

Aerial Refueling (Tanker)
Airspeed, pressure altitude, outside air temp
Boom and probe - axial, torsional, and bending load
Tanker fuel flow
Fuel pump discretes (ON/OFF)
Aerial refueling pumps outlet pressures (1 each pump)
Tanker fuel delivery pressure and temp
Hydraulic pump pressure driving refueling pumps
Boom position (azimuth, elevation, extension)
Boom control stick forces (2 axes)
Boom control surface position (ruddervator)
Telescope lever position
Total fuel transferred (tanker)
Video tape recording or motion picture or boom/receptable interface
Discrete for contact/disconnect

<u>Add for KC-10 Tanker</u>
Automatic Load Alleviation System state
Disconnect limit settings (delay, roll, pitch)
Boom nozzle vertical and lateral load

<u>Add for Hose Reel</u>
Hose length
Hose fuel pressure
Hose reel fuel pump hydraulic pressure
Hose reel hydraulic reference pressure
Hose reel drag strut load

<u>Icing and Rain</u>

Video/Photo
Embedded engines and low radar cross section vanes (video)
Photo of ice accretion, shedding (24 to 400 frames/sec) - 2 cameras

Ice Indicators
Depth gauges - 1 per surface to be iced
Paint schemes (for accretion limits) - 1 per surface to be iced
Detectors/severity indicators (discrete) (use existing probes)

Anti-Ice/Deice Systems

Electrical
Skin thermocouples - average of 20
Power output (3 - phase, Vdc, current)
Cycles (discrete) - on and off
Thermal (bleed air)
Skin thermocouples - average of 20
Valve position (discrete)
Pressure and temp for flow calculation (1 each) or flow rate

Pneumatic (boot type)
Cycles - (discrete) - on and off
Pressures - 1 per source

Impulse/Hybrid
Cycles - (discrete) - on and off
Power output (phase, Vdc, current)
Alcohol/glycol
Fluid flow rate
Skin thermocouples - average of 20
Fluid pressure

Cloud Characteristics
Liquid water content
Water droplet spectra (medium volumetric diameter, distribution)
Separation distance
Relative humidity

Tanker Parameters
Water/airflow, pressures and temps

8.3 Task vs Climatic Condition

An effective method for establishing the combined procedures for each test run is to develop a task versus climatic condition matrix. A typical metrix for the Climatic Laboratory is presented in Table 7. This matrix was constructed by combining all the tasks detailed in the integrated test plan for each test condition. This matrix is considered absolutely essential and can be used to track objectives accomplished and to provide a basis for report preparation. The main use, however, is to minimize the effort for establishing combined test procedures for a given test run.

Table 7.
Task vs Climatic Condition

OBJ NO.	SYSTEM TEST (Deg C)	70 (21)	85 (29)	24-35 (-4 to .2)	110 (43)	125 (52)	70 (21)	0 (-18)	-20 (-29)	-40 (-40)	0 (-18)	70 (21)
		Ambient Temperature (Deg F)										
	HYDRAULIC SYSTEM											
01	General (No Special tests)	ab	ab	ab	ab	ab	ab	ab	ab	ab	--	ab
02	JFS/Engine Start	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
03	System Warmup (Pre Takeoff)	a	a	a	a	a	a	ab	ab	ab	--	a
04	Extended Ground Idle	a	--	--	ab	ab	ab	--	--	--	--	--
05	Max Rate Flight Control Inputs	a	--	--	a	a	a	a	ab	ab	a	a
06	Hyd Power During Gun Firing	b	b	--	b	b	b	--	ba	b	--	b
07	Aerial Refueling Door & Latch	a	a	a	a	a	a	a	a	a	a	a
08	Emergency Power Unit	--	--	--	--	--	b	--	b	b	--	b
	COMM/NAV											
01	UHF Comm	a	a	--	--	a	a	--	--	a	--	a
02	Intercomm	a	a	--	--	a	a	--	--	a	--	a
04	IFF	a	a	--	--	a	a	--	--	a	--	a
05	TACAN	a	a	--	--	a	a	--	--	a	--	a
07	ILS	a	a	--	--	a	a	--	--	a	--	a
09	INS	ab	--	--	ab	ab	ab	ab	ab	ab	--	ab
	ARMAMENT SYSTEM											
01	Gun System Evaluation											
	a. Dummy Ammo	a	a	a	--	a	a	a	a	a	--	a
	b. Live Ammo	b	b	b	--	b	b	b	b	b	--	b
	c. Insp-Chaff/Flare Disp	ab	ab	ab	--	--	--	ab	ab	ab	--	ab
02	Armament Control System											
	a. Selective Jettison Tests	a	a	--	--	a	a	a	--	a	--	a
	b. HFT&E Store Loadings	--	--	--	--	ab	ab	--	--	ab	--	--
03	Evaluate GSE (No Special Tests)	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
04	Maint-R&R Gun, Stores Panel	--	b	--	--	--	--	a	--	--	--	--
	ENVIRONMENTAL CONTROL SYSTEM (ECS)											
01	Cabin Vent and Leak Rate Check	--	--	--	--	a	--	--	--	--	--	--
01	Cabin Pressure Test	--	--	--	--	--	a	a	a	a	--	a
07	Cabin Temp Control	a	--	--	a	a	a	a	a	a	--	a
08	Normal ECS Temp Distribution	a	a	--	a	a	a	--	--	--	--	a
09	Equipment Cooling	a	a	--	a	a	a	--	--	--	--	a
10	Water Separator	--	a	--	--	--	--	--	--	--	--	--
12	Heat Exchanger	a	--	--	a	a	a	--	--	--	--	--

Notes: a denotes day-1 test
b denotes day-2 test

Table 7.
Task vs Climatic Condition (Continued)

OBJ NO.	SYSTEM TEST (Deg C)	Ambient Temperature (Deg F) 70 (21)	85 (29)	24-35 (-4 to 2)	110 (43)	125 (52)	70 (21)	0 (-18)	-20 (-29)	-40 (-40)	0 (-18)	70 (21)
	LANDING GEAR AND ARRESTING SYSTEMS											
01	Landing Gear Retract	a	b	a	a	ab	a	a	ab	ab	ab	a
01	Landing Gear Ext/Ret Cycles	—	—	—	—	—	a	a	a	a	—	a
01	Landing Gear Emergency Ext	b	b	—	b	b	b	b	b	b	b	b
02	Nose Wheel Steering	a	—	—	—	—	—	a	a	a	—	—
03	Brake (Anti-Skid/Parking)	a	a	—	a	a	a	a	a	a	—	a
06	Landing Gear Servicing	a	a	a	a	a	a	a	a	a	a	a
	A/A MISSILE MODES AND EM CUES											
01	A/A Missile Mode	a	a	—	a	a	a	a	a	a	—	a
02	Combat EM Cues	a	a	—	a	a	a	a	a	a	—	a
	FUEL SYSTEM											
01	Ground Refuel/Defuel	b	b	—	b	b	b	—	b	b	—	b
02	Fuel Expansion	—	—	—	—	a	—	—	—	—	a	a
03	Extended Ground Idle	a	—	—	a	a	a	—	—	—	—	—
04	Fuel Tank Exp Suppress	—	—	—	—	—	—	—	—	a	—	—
05	Air Vent & Fuel Drain	—	—	—	—	—	—	—	—	a	—	—
06	Degraded Fuel System	b	b	—	b	b	b	—	—	—	—	—
	PROPULSION SYSTEM											
01	JFS Ground Start	ab	ab	ab	ab	ab	ab	ab	ab	ab	—	ab
02	Engine Ground Start	ab	ab	ab	ab	ab	ab	ab	ab	ab	—	ab
03	ADG/IDG Overtemp Evaluation	—	—	—	—	ab	—	—	—	—	—	—
04	Engine H_2O Ingestion	—	b	—	—	—	b	—	—	—	—	—
	EMERGENCY POWER UNIT (EPU)											
01	Hydrazine Operations	b	b	—	b	b	b	b	ab	ab	—	b
02	Bleed Air Operations	a	a	—	a	a	a	a	a	ab	—	a
03	Augment Mode Operations	a	a	—	a	a	a	a	a	ab	—	a

Notes: a denotes day-1 test
b denotes day-2 test

Table 7.
Task vs Climatic Condition (Concluded)

OBJ NO.	SYSTEM TEST	Ambient Temperature (Deg F) (Deg C) 70 (21)	85 (29)	24–35 (-4 to 2)	110 (43)	125 (52)	70 (21)	0 (-18)	-20 (-29)	-40 (-40)	0 (-18)	70 (21)
	GENERAL SUBSYSTEMS											
01	FCS Servoactuator Tests	b	—	b	—	b	b	b	b	b	b	b
02	FCS Self Test Ops Suit	a	a	—	—	a	a	a	a	a	—	a
03	FCS Maint Character	a	a	a	—	a	a	—	—	a	—	a
04	Electrical Systems Test											
	a. EPU Hydrazine Mode	b	b	—	—	b	b	—	b	—	—	b
	b. EPU Augment Mode	a	a	—	—	a	a	a	a	a	—	a
	c. Canopy Cycles on Battery	a	—	a	a	a	a	a	—	a	—	a
05	Lighting System Ops Suit	b	b	b	b	b	b	b	b	b	b	b
06	HUD Ops Suit	a	a	a	a	a	a	a	a	a	a	a
07	RADAR/REO/Threat Warning	a	a	a	a	a	a	a	a	a	a	a
	AIRFRAME											
01	Canopy	a	a	a	a	a	a	a	a	a	a	a
02	Mooring/Jacking	a	a	a	a	a	a	a	a	a	a	a
03	Water Tightness	—	b	b	—	—	—	—	—	—	—	—
04	Rain Repellent	—	ab	—	—	—	—	—	—	—	—	—
05	De-icing	—	—	ab	—	—	—	ab	ab	ab	ab	ab
06	Structures (Insp)	—	—	—	—	—	—	—	—	—	—	a
07	Corrosion/Deterioration	b	b	b	b	b	b	b	b	b	b	

Notes: a denotes day-1 test
b denotes day-2 test

8.4 Visit Locations During Fact-finding Trips

Factfinding trips were made to a number of locations where personnel operate equipment in severe climatic conditions or where people reside who had experience in operating or testing in extreme climatic conditions. A list of these locations is contained in Table 8.

Table 8

Visit Locations During Factfinding Trips
(Points of Contact)

1. 343rd Tactical Fighter Wing/MA
Eielson AFB, Alaska 99702
(CMSgt Jerry Walden, Mr Jed Grover)

2. 5th Bombardment Wing
Minot AFB, North Dakota 58705-5000
(Capt Terry Gribben)

3. 3246th Test Wing/TFLT
Climatic Laboratory
Eglin AFB, Florida 32542-5000
(Mr Lorin Klein)

4. 4950th Test Wing
Wright-Patterson AFB, Ohio 45433-6513
(Mr Ronald Stanford)

5. U.S. Army Aviation Development Test Activity
STEBG-TD
Cairns Army Air Field, Alabama 36362-5276
(Mr Roy Miller)

6. Naval Air Test Center
Code CT-23
Patuxent River, Maryland 20670-5000
(Mr Tony Rossetti)

7. Antarctic Development Squadron, VXE-6
Naval Air Station
Point Mugu, California 93042-5000
(LCDR Hibbler)

8. VA-174 Detachment
Naval Air Facility
El Centro, California 92243-5000
(Lt James Sherman)

9. U.S. Army Tropic Test Center
STETC-MTD-O
Fort Clayton, Panama
APO Miami, Florida 34004
(Mr Juan M. Calderon)

10. Aerospace Engineering Test Establishment
Canadian Forces Base Cold Lake
Medley, Alberta, Canada TOA2MO
(Capt Luc Deneger)

11. Inspector General
Royal Danish Air Force
P.O. Box 202
2950 Vedback, Denmark
(Lt Col Kasper Vilsen)

12. Aeroplane and Armament Experimental Establishment
Performance and Trials Management Division
Boscomb Down
Salisbury, Wilts SP4 OJF
United Kingdom
(Mr E. J. Bull)

13. Centre D'Essais EnVol
13128 Istres Air France
(Mr Paul Badaille)

Annex 1

AGARD FLIGHT TEST INSTRUMENTATION AND FLIGHT TEST TECHNIQUES SERIES

1. Volumes in the AGARD Flight Test Instrumentation Series, AGARDograph 160

Volume Number	*Title*	*Publication Date*
1.	Basic Principles of Flight Test Instrumentation Engineering by A.Pool and D.Bosman (to be revised in 1989)	1974
2.	In-Flight Temperature Measurements by F.Trenkle and M.Reinhardt	1973
3.	The Measurement of Fuel Flow by J.T.France	1972
4.	The Measurement of Engine Rotation Speed by M.Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E.Bennett	1974
6.	Open and Closed Loop Accelerometers by I.Mclaren	1974
7	Strain Gauge Measurements on Aircraft by E.Kottkamp, H.Wilhelm and D.Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C.van der Linden and H.A.Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G.van Nunen and G.Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R.Ferrell	1980
11.	Pressure and Flow Measurement by W.Wuest	1980
12.	Aircraft Flight Test Data Processing — A Review of the State of the Art by L.J.Smith and N.O.Matthews	1980 1980
13.	Practical Aspects of Instrumentation System Installation by R.W.Borek	1981
14.	The Analysis of Random Data by D.A.Williams	1981
15.	Gyroscopic Instruments and their Application to Flight Testing by B.Stieler and H.Winter	1982
16.	Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications by P.de Benque d'Agut, H.Riebeek and A.Pool	1985
17.	Analogue Signal Conditioning for Flight Test Instrumentation by D.W.Veatch and R.K.Bogue	1986

Volume Number	*Title*	*Publication Date*
18.	Microprocessor Applications in Airborne Flight Test Instrumentation by M.J.Prickett	1987

At the time of publication of the present volume the following volume was in preparation:

Digital Signal Conditioning for Flight Test Instrumentation
by G.A.Bever

2. Volumes in the AGARD Flight Test Techniques Series

Number	*Title*	*Publication Date*
AG 237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes will be published as a sequence of Volume Numbers of AGARDograph 300.

Volume Number	*Title*	*Publication Date*
1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A.Lawford and K.R.Nippress	1983
2.	Identification of Dynamic Systems by R.E.Maine and K.W.Iliff	1985
3.	Identification of Dynamic Systems — Applications to Aircraft Part 1: The Output Error Approach by R.E.Maine and K.W.Iliff	1986
4.	Determination of Antenna Patterns and Radar Reflection Characteristics of Aircraft by H.Bothe and D.Macdonald	1986
5.	Store Separation Flight Testing by R.J.Arnold and C.S.Epstein	1986
6.	Developmental Airdrop Testing Techniques and Devices by H.J.Hunter	1987
7.	Air-to-Air Radar Flight Testing by R.E.Scott	1988
8.	Flight Testing under Extreme Environmental Conditions by C.L.Hendrickson	1988

At the time of publication of the present volume the following volumes were in preparation:

Identification of Dynamic Systems. Applications to Aircraft
Part 2: Nonlinear Model Analysis and Manoeuvre Design
by J.A.Mulder and J.H.Breeman

Flight Testing of Digital Navigation and Flight Control Systems
by F.J.Abbink and H.A.Timmers

Aircraft Noise Measurement and Analysis Techniques
by H.H.Heller

Flight Testing of Terrain Following Systems
by C.Dallimore and M.K.Foster

Store Ballistic Analysis and Testing
by R.Arnold and H.Reda

Annex 2

AVAILABLE FLIGHT TEST HANDBOOKS

This annex is presented to make readers aware of handbooks that are available on a variety of flight test subjects not necessarily related to the contents of this volume.

Requests for A & AEE documents should be addressed to the Defence Research Information Centre, Glasgow (see back cover). Requests for US documents should be addressed to the Defence Technical Information Center, Cameron Station, Alexandria, VA 22314 (or in one case, the Library of Congress).

Number	*Author*	*Title*	*Date*
NATC-TM76-ISA	Simpson, W.R.	Development of a Time-Variant Figure-of-Merit for Use in Analysis of Air Combat Maneuvring Engagements	1976
NATC-TM76-3SA	Simpson, W.R.	The Development of Primary Equations for the Use of On-Board Accelerometers in Determining Aircraft Performance	1977
NATC-TM-77-IRW	Woomer, C. Carico, D.	A Program for Increased Flight Fidelity in Helicopter Simulation	1977
NATC-TM-77-2SA	Simpson, W.R. Oberle, R.A.	The Numerical Analysis of Air Combat Engagements Dominated by Maneuvering Performance	1977
NATC-TM-77-1SY	Gregoire, H.G.	Analysis of Flight Clothing Effects on Aircrew Station Geometry	1977
NATC-TM-78-2RW	Woomer, G.W. Williams, R.L.	Environmental Requirements for Simulated Helicopter/ VTOL Operations from Small Ships and Carriers	1978
NATC-TM-78-1RW	Yeend, R. Carico, D.	A Program for Determining Flight Simulator Field-of-View Requirements	1978
NATC-TM-79-33SA	Chapin, P.W.	A Comprehensive Approach to In-Flight Thrust Determination	1980
NATC-TM-79-3SY	Schiflett, S.G. Loikith, G.J.	Voice Stress Analysis as a Measure of Operator Workload	1980
NWC-TM-3485	Rogers, R.M.	Six-Degree-of-Freedom Store Program	1978
WSAMC-AMCP 706-204	—	Engineering Design Handbook, Helicopter Performance Testing	1974
NASA-CR-3406	Bennett, R.L. and Pearsons, K.S.	Handbook on Aircraft Noise Metrics	1981
—	—	Pilot's Handbook for Critical and Exploratory Flight Testing. (Sponsored by AIAA & SETP — Library of Congress Card No.76-189165)	1972
—	—	A & AEE Performance Division Handbook of Test Methods for assessing the Flying Qualities and Performance of Military Aircraft. Vol.1 Airplanes	1979
A & AEE Note 2111	Appleford, J.K.	Performance Division: Clearance Philosophies for Fixed Wing Aircraft	1978
A & AEE Note 2113 (Issue 2)	Norris, E.J.	Test Methods and Flight Safety Procedures for Aircraft Trials Which May Lead to Departures from Controlled Flight	1980

Number	*Author*	*Title*	*Date*
AFFTC-TD-75-3	Mahlum, R.	Flight Measurements of Aircraft Antenna Patterns	1973
AFFTC-TIH-76-1	Reeser, K. Brinkley, C. and Plews, L.	Inertial Navigation Systems Testing Handbook	1976
AFFTC-TIH-79-1	—	USAF Test Pilot School (USAFTPS) Flight Test Handbook Performance: Theory and Flight Techniques	1979
AFFTC-TIH-79-2	—	USAFTPS Flight Test Handbook, Flying Qualities: Theory (Vol.1) and Flight Test Techniques (Vol.2)	1979
AFFTC-TIH-81-1	Rawlings, K., III	A Method of Estimating Upwash Angle at Noseboom-Mounted Vanes	1981
AFFTC-TIH-81-1	Plews, L. and Mandt, G.	Aircraft Brake Systems Testing Handbook	1981
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Number EPNER Reference	*Author*	*Title*	*Price (1983) French Francs*	*Notes*
2	G.Leblanc	L'analyse dimensionelle	20	Réédition 1977
7	EPNER	Manuel d'exploitation des enregistrements d'Essais en vol	60	6ème Edition 1970
8	M.Durand	La mécanique du vol de l'hélicoptère	155	1ère Edition 1981
12	C.Laburthe	Mécanique du vol de l'avion appliquée aux essais en vol	16	Réédition en cours
15	A.Hisler	La prise en main d'un avion nouveau	50	1ère Edition 1964
16	Candau	Programme d'essais pour l'évaluation d'un hélicoptère et d'un pilote automatique d'hélicoptère	20	2ème Edition 1970
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24	G.Fraysse F.Cousson	Pratique des essais en vol (en 3 Tomes)	T1 – 160 T2 – 160 T3 – 120	1ère Edition 1973
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26	J.C.Wanner	Bang sonique	60	
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88	Richard	Technologie hélicoptère	95	Réédition 1971

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The major objective of Flight Testing under extreme environmental conditions is to determine to what extent a weapon system, including its essential support equipment and attendant crews can accomplish the design mission in the required climatic extremes, using Technical Order procedures. Such testing has historically often revealed design deficiencies that impact the operational capabilities of the air vehicle involved.

This volume in the AGARD Flight Test Techniques Series discusses the philosophy, purpose and methods for conducting ground and flight tests of weapon systems in extreme environmental conditions. The areas considered include testing in a controlled artificial environment, as well as cold arctic, hot desert, tropic, and adverse-weather conditions. Also included are the technical and safety aspects of planning, instrumentation and data acquisition requirements, types of tests conducted and reporting requirements. Nato furnished, (RW)

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